U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-285 662

Source Assessment: Chemical and Fertilizer Mineral Industry, State-of-the-Art

Monsanto Research Corp, Dayton, Ohio

Prepared for

Industrial Environmental Research Lab -Cincinnati, Edison, N J

Jun 78

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-78-004p
June 1978

Research and Development

PB 285 662

EPA

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Chemical and Fertilizer Mineral Industry, State of the Art

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-78-004p	2.	3. RECIPIENT'S ACCESSION NO. PB285662
4. TITLE AND SUBTITLE Source Assessment: Chemical and Fertilizer Mineral Industry, State of the Art		5. REPORT DATE June 1978 issuing date
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J. C. Ochsner and T. R. Blackwood		8. PERFORMING ORGANIZATION REPORT NO. MRC-DA-773
9. PERFORMING ORGANIZATION NAME AND ADDRESS Monsanto Research Corporation 1515 Nicholas Road Dayton, Ohio 45407		10. PROGRAM ELEMENT NO. 1BB-610
		11. CONTRACT/GRANT NO. 68-02-1874
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Lab., CINN, OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 10/76 to 8/77
		14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

IERL-Ci task leader for this report is S. Jackson Hubbard, 513-684-4417

16. ABSTRACT

This report describes a study of air and water pollutants emitted by the chemical and fertilizer mineral industry. The potential environmental effect of the source was evaluated using a hazard ratio (defined as the ratio of the maximum time-averaged ground level concentration to an ambient air quality standard for air and the ratio of discharge rate to a water quality criteria for water).

Air and water pollutants are generated during the conversion of naturally occurring minerals into suitable forms for use in chemical and fertilizer production. These minerals are barite, borates, fluorspar, lithium minerals, mineral pigments, phosphate rock, potash, salt, sodium sulfate, sulfur, and trona ore.

The four significant wastewater problem areas in the mining and beneficiation of minerals in the chemical and fertilizer industry are mine water drainage, wastewater from the fluorspar industry, phosphate rock slimes, and sulfur bleedwater brines.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Beneficiation Fertilizers Mining Engineering Emission Air Pollution Water Pollution	Chemicals Phosphate Brine Minerals	68D

18. DISTRIBUTION STATEMENT Release to the Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 137.
	20 SECURITY CLASS *(This page)* Unclassified	22. PRICE PCA07/MF A01

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978—757-140/1360

EPA-600/2-78-004p
June 1978

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State of the Art

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of air emissions and water pollutants from the chemical and fertilizer mineral industry. This study was conducted to provide a better understanding of the distribution and characteristics of emissions and effluents from this source. Further information on this subject may be obtained from the Extraction Technology Branch, Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and solid waste legislation. If control technology is unavailable, inadequate, or uneconomical, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for developing control technology for a large number of operations (more than 500) in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries that represent sources of pollutants in accordance with EPA's responsibility, as outlined above. Dr. Robert C. Binning serves as MRC Program Manager in this overall program, entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer for this series. Reports prepared in this program are of two types: Source Assessment Documents and State-of-the-Art Reports.

Source Assessment Documents contain data on pollutants from specific industries. Such data are gathered from the literature, government agencies, and cooperating companies. Sampling and analyses are also performed by the contractor when the available information does not adequately characterize the source pollutants. These documents contain all of the information necessary for IERL to decide whether a need exists to develop additional control technology for specific industries.

State-of-the-Art Reports include data on pollutants from specific industries which are also gathered from the literature, government agencies, and cooperating companies. However, no extensive sampling is conducted by the contractor for such industries. Sources in this category are considered by EPA to be of insufficient priority to warrant complete assessment for control technology decision making. Therefore, results from such studies are published as State-of-the-Art Reports for potential utility by the government, industry, and others having specific needs and interests.

This study was undertaken to provide information on air emissions and water pollutants from the chemical and fertilizer mineral industry. The work was performed for the Extraction Technology Branch, Resource Extraction and Handling Division, Industrial Environmental Research Laboratory, Cincinnati. Mr. S. Jackson Hubbard served as EPA Task Officer.

ABSTRACT

This report describes a study of air and water pollutants emitted by the chemical and fertilizer mineral industry. The potential environmental effect of the source was evaluated using a hazard ratio (defined as the ratio of the maximum time-averaged ground level concentration to an ambient air quality standard for air and the ratio of discharge rate to a water quality criteria for water).

Air and water pollutants are generated during the conversion of naturally occurring minerals into suitable forms for use in chemical and fertilizer production. These minerals are barite, borates, fluorspar, lithium minerals, mineral pigments, phosphate rock, potash, salt, sodium sulfate, sulfur, and trona ore. The representative plant size for each mineral, except borates, was determined by dividing the total annual production by the number of plants. (In the case of borates, one plant which accounts for over 75% of annual production was considered representative.)

The emission factor for respirable particulates emitted from the representative source ranges from 0.02 g/metric ton for sulfur to 110 g/metric ton for potash. The hazard ratio for respirable particulates emitted from the representative source ranges from 0.00005 for sulfur to 0.9 for potash. Total particulate emissions from the production of chemical and fertilizer minerals contribute 0.2% of the national emissions burden.

Hazard ratios for water pollutants were developed only for the phosphate rock industry as it was the only industry for which complete information was available concerning river flow rate and concentration. For a representative source, the hazard ratios of elemental phosphorous, fluoride, and total suspended solids (TSS) are 0.061, 0.051, and 0.0025, respectively.

The four significant wastewater problem areas in the mining and beneficiation of minerals in the chemical and fertilizer industry are mine water drainage, wastewater from the fluorspar industry, phosphate rock slimes, and sulfur bleedwater brines. The Florida phosphate rock slimes problem may well be the most important of all fertilizer production problems. Suspended solids are the principal pollutant in chemical and fertilizer wastewater discharges. While a variety of treatment technologies are available for removing suspended solids, only a small number are widely

used.

used. The unlined settling pond is the most widely used form of control technology.

This report was submitted in partial fulfillment of Contract 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1976 to August 1977, and work was completed as of March 1978.

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ABBREVIATIONS AND SYMBOLS

C_D -- concentration of the discharge

D -- representative distance from the source

D_{SP} -- distance from plant at which hazard ratio equals 0.1

F -- hazard factor (ambient air quality standard)

HMS -- heavy media separation

LC_{50} -- lethal concentration which causes 50% mortality in the test species

m_1, m_2 -- slopes used in calculating distances to samplers

NIOSH -- National Institute of Occupational Safety and Health

NO_x -- nitrogen oxides

Q -- representative mass emission rate

S_A -- hazard ratio for air

S_P -- hazard ratio for respirable particulates

S_W -- hazard ratio for water effluent

$S_{0,1,2,3,4}$ -- high-volume sampler locations

TLV -- threshold limit value

u -- average wind speed

V_D -- volumetric flow rate of river discharge

V_R -- volumetric flow rate of the river

x_i, y_i -- Cartesian coordinates used to relate position of ith sampler to the source

X_i, Y_i -- downwind and lateral distance, respectively, from source along the dispersion centerline

Θ -- angle of mean wind speed

π -- 3.1416

σ_y -- standard deviation in the horizontal of the plume concentration distribution

σ_z -- standard deviation in the vertical of the plume concentration distribution

$\overline{\chi}_{max}$ -- maximum time-averaged downwind concentration

CONVERSION FACTORS AND METRIC PREFIXES[a]

CONVERSION FACTORS

To convert from	To	Multiply by
Degree Celsius (°C)	Degree Fahrenheit	$t_{°F} = 1.8\ t_{°C} + 32$
Kilogram (kg)	Ton (short, 2,000 lb mass)	1.102×10^{-3}
Kilogram (kg)	Pound-mass (avoirdupois)	2.204
Kilometer^2 (km^2)	Mile^2	3.860×10^{-1}
Meter (m)	Foot	3.281
Meter^2 (m^2)	Foot^2	1.076×10^{1}
Meter^3 (m^3)	Gallon (U.S. liquid)	2.642×10^{2}
Meter^3 (m^3)	Foot^3	3.531×10^{1}
Metric ton	Pound-mass	2.205×10^{3}
Radian (rad)	Degree	5.730×10^{1}

PREFIXES

Prefix	Symbol	Multiplication factor	Example
Kilo	k	10^{3}	1 kg = 1×10^{3} grams
Milli	m	10^{-3}	1 mm = 1×10^{-3} meter
Micro	μ	10^{-6}	1 g = 1×10^{-6} gram

---

[a] Metric Practice Guide. ANSI/ASTM Designation: E 380-76$^{\varepsilon}$, IEEE Std 268-1976, American Society for Testing and Materials, Philadelphia, Pennsylvania, February 1976. 37 pp.

SECTION 1

INTRODUCTION

The conversion of naturally occurring mineral deposits into chemicals and fertilizers involves surface and underground mining and a variety of beneficiation steps. Air and water pollution is produced by individual sources (unit operations) during mining, processing, and material transfer activities.

An investigation of the chemical and fertilizer mineral industry was conducted to provide an understanding of the distribution and characteristics of the air pollution emissions and wastewater effluents. Data collection emphasized the accumulation of sufficient information to ascertain the need for developing control technology.

Information came from the literature, federal and state environmental agencies, and personal contacts with industry.

This document contains information on:

- Emission sources and composition.
- Geographical distribution and production figures for the minerals under study.
- Air emission levels as obtained by direct sampling for the phoshate rock and potash industries.
- A method to estimate the air emission levels due to chemical and fertilizer mineral unit operations.
- Wastewater effluent concentrations and characteristics.
- Hazard ratios of air emissions and wastewater effluents.
- Types of control technology used and proposed for air and water pollutants.
- Trends in the demand and production of chemical and fertilizer minerals.

Particular attention is paid to the phosphate rock industry due to its predominant size in relation to other mineral productions.

Items of special interest to the reader may be Sections 4 and 5, Emissions and Control Technology. In addition, a discussion of major wastewater problem areas is given in Appendix D.

SECTION 2

SUMMARY

The chemical and fertilizer mineral industry converts naturally occurring minerals into forms suitable for use in chemical and fertilizer production. During this conversion, air and water pollutants are generated. The minerals are barite, borates, fluorspar, lithium minerals, mineral pigments, phosphate rock, potash, salt, sodium sulfate, sulfur, and trona ore. The purpose of this document is to aid the U.S. Environmental Protection Agency in determining the need to develop new control technology for the industry, with particular emphasis on the future.

The chemical and fertilizer mineral industry is necessary to our national well-being, particularly with its basic tie-in to food production. For example, over 90% of the phosphate produced in Florida is used in agriculture.

Table 1 presents some important features of the industry which will be referred to in the subsequent discussion.

For each mineral, except borates, the representative plant size given in Table 1 was determined by dividing the total annual production by the number of plants. (In the case of borates, one plant which accounts for over 75% of annual production was considered representative.) Of course the actual size of plants in an industry may vary considerably. The representative plant size is an average value used to determine a representative mass emission rate.

Other important features to note:

- Chemical and fertilizer mineral operations are typically conducted in relatively isolated regions where the population density is usually less than 50 persons/km^2.

- The combined annual production for 7 of 11 minerals accounts for only 7% of the total chemical and fertilizer mineral industry.

- The major air pollutant of concern emitted during the production of chemical and fertilizer minerals is respirable (less than 7-μm geometric mean diameter) particulate matter.

TABLE 1. SALIENT FEATURES OF THE CHEMICAL AND FERTILIZER MINERAL INDUSTRY

Mineral	Number of principal sites	Annual production, metric tons	Representative plant size, metric tons/yr	Emission rate of respirable particulates, g/s	Hazard ratio for respirable particulates	Contribution to national emission burden of total particulates, %	Average population density of major producing areas, persons/km^2	Emission factor for respirable particulates, g/metric ton
Barite	24	1,167,000^a	50,000	0.05	0.004	0.001	10	17
Borates	3	1,063,000^b	800,000	0.90	0.07	0.001	10	21
Fluorspar	11	111,000^b	10,000	0.02	0.002	0.0002	80	36
Lithium	4	12,000^c	3,000	0.002	0.0002	0.000007	120	10
Mineral pigments (Iron oxide pigments)	15	63,500^d	4,000	0.004	0.0003	0.0001	100	20
Phosphate rock	23	44,276,000^b	2,000,000	4.0	0.3	0.10	50	37
Potash	7^e	13,479,000^{b,e}	2,000,000	12.0	0.9	0.10	3	110
Brine salt	37	20,900,000^c	600,000	0.30	0.02	0.01	50	9
Rock salt	19	12,160,000^c	600,000	0.04	0.003	0.0007	60	1.2
Evaporated salt	11	4,940,000^c	450,000	0.20	0.02	0.003	20	9
Sodium sulfate	5	1,864,000^f	400,000	0.20	0.02	0.001	10	7.3
Sulfur	13	7,325,000^b	600,000	0.0006	0.00005	0.000009	30	0.02
Trona ore	3	3,682,000^a	1,000,000	0.60	0.05	0.002	1	11
Total	170	112,683,500				0.2		

[a] 1974 production. [b] 1975 production. [c] 1976 production. [d] 1972 production. [e] Includes only New Mexico mines. [f] 1973 production.

The hazard or pollution potential of a representative source may be assessed by the use of a hazard ratio.

The hazard ratio for an air pollutant, S_A, is the ratio of the maximum time-averaged ground level concentration to an ambient air quality standard:

$$S_A = \frac{\bar{\chi}_{max}}{F} \qquad (1)$$

where $\bar{\chi}_{max}$ = maximum time-averaged ground level concentration
F = hazard factor (ambient air quality standard)

For ground level sources, the hazard ratio for respirable particulates, S_p, is:

$$S_p = \frac{4{,}020\ Q}{D^{1.814}} \qquad (2)$$

where Q = representative mass emission rate, g/s
D = representative distance from the source, m
(for the purposes of Table 1, D = 400 m)

As can be seen, hazard ratios for phosphate rock and potash are at least an order of magnitude larger than those for any other mineral. Other minerals may produce air emissions more toxic than respirable particulate matter, but the volume of emissions from the phosphate rock and potash industries is large enough to overshadow them.

Of the total particulate emission from the phosphate rock industry, approximately 44% is caused by loading of railroad hopper cars. The industry is aware of the problem, and companies are individually devising schemes to handle the situation. It is estimated that by 1980, application of the best available control technology will reduce air emissions by 26%.

Two items of interest which concern fluoride and radioactive pollution from phosphate mining are noted. Fluoride compounds (reported as fluorine) account for about 5% of the emissions. The concentration in the emissions and the rock being mined are not significantly different. Uranium concentrations, which vary directly with the phosphate concentration of phosphate rock, usually are 40 to 165 g/metric ton[a] of rock. More study may be needed to better define radioactive pollution from phosphate mining.

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[a] 1 metric ton equals 10^6 grams; conversion factors and metric system prefixes are presented in the prefatory material.

At the time of this writing, the state of New Mexico is implementing control regulations concerning the potash industry. It is evident that further control will be necessary. The question which remains for the industry is: How much?

The emissions from Ozark submerged-combustion evaporators are a major problem for the two Carlsbad, New Mexico, facilities which process langbeinite ore. Prior particle size measurements show that all the particles in such emissions are less than 7 μm. A study is currently in progress to assess the application of Monsanto's BRINK® fine particle eliminators to the problem. Once this problem area is solved, it is believed that the necessary control technology will exist for the potash industry.

To summarize the state of control technology for the chemical and fertilizer industry, it appears that the necessary controls exist and are being applied by the industry to control air and water pollution. The trend in fugitive emission control (a relatively new area of environmental concern) points toward the enclosure of emission points such as railroad car loading and storage. Particulate emissions from the production of chemical and fertilizer minerals have been estimated to be 0.2% of the overall national emission.

The hazard ratio for a water pollutant, S_W, is the ratio of discharge rate to a water quality criteria. The river concentration is taken into effect so that what is being considered is an excess relative dose.

The hazard ratio is defined as

$$S_W = \frac{V_D C_D}{\left(V_R + V_D\right)F} \tag{3}$$

where S_W = hazard ratio for water effluent
V_D = volumetric flow rate of the discharge, m^3/s
C_D = concentration of the discharge, mg/m^3
V_R = volumetric flow rate of the river, m^3/s
F = hazard factor; EPA water quality criteria or 0.01 of the LC_{50}[a] (96-hr)

The list of hazard ratios for water includes only those for the phosphate rock industry. It was the only industry for which complete information was available concerning river flow rate and concentration. For a representative source, discharging into Florida's Peace River, the hazard ratios of elemental phosphorus, fluoride, and total suspended solids (TSS) are 0.061, 0.051, and 0.0025, respectively.

---

[a] LC_{50} is the lethal concentration which causes 50% mortality in the test species.

There are four significant wastewater problem areas in the mining and beneficiation of minerals for the chemical and fertilizer industry. They are:

- Mine water drainage
- Wastewater from the fluorspar industry
- Phosphate rock slimes
- Sulfur bleedwater brines

Suspended solids are the principal pollutant in wastewater discharges. Treatment technologies available for removing suspended solids are varied, but only a small number are widely used. The unlined settling pond is, by far, the most widely used form of control technology.

The Florida phosphate rock slimes problem may well be the most important of all fertilizer production problems. The industry has been active for a number of years to devise methods for dewatering the slimes, but until available schemes become economically feasible, settling ponds will be widely used.

SECTION 3

SOURCE DESCRIPTION

PROCESS DESCRIPTION

Materials used in the chemical and fertilizer industries include a number of different mineral compositions, so industry mining practices involve a spectrum of conventional surface and underground methods. Processing also varies to some degree, being dependent upon the particular mineral or product.

Typical unit operations, used by the industry as a whole, include:

- Drilling
- Blasting
- Quarrying
- Truck loading and unloading
- Dragline operation
- Conveying
- Crushing and grinding
- Screening
- Flotation
- Thickening
- Filtering
- Evaporation
- Drying
- Bagging
- Storage

These minerals may be placed in four categories according to their processing operations. Block diagrams for each category are given in Figures 1 through 4.

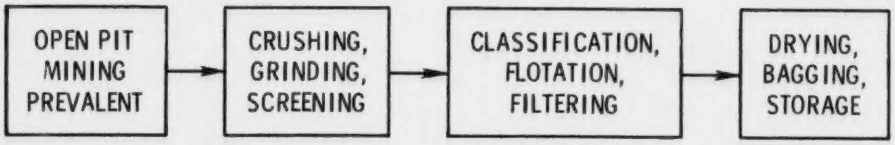
OPEN PIT MINING PREVALENT
CRUSHING, GRINDING, SCREENING
CLASSIFICATION, FLOTATION, FILTERING
DRYING, BAGGING, STORAGE

Figure 1. Barite, fluorspar, phosphate rock, lithium minerals, and mineral pigments.

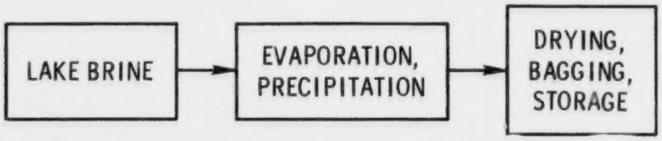
LAKE BRINE
EVAPORATION, PRECIPITATION
DRYING, BAGGING, STORAGE

Figure 2. Brine minerals: borax, natural soda ash, lithium salts, salt, and potash.

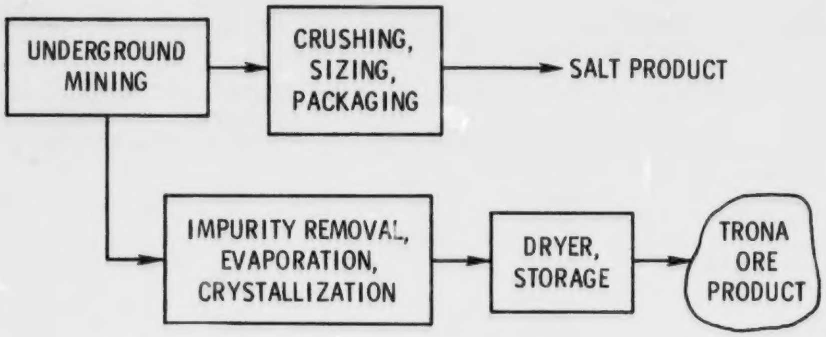
UNDERGROUND MINING
CRUSHING, SIZING, PACKAGING
SALT PRODUCT
IMPURITY REMOVAL, EVAPORATION, CRYSTALLIZATION
DRYER, STORAGE
TRONA ORE PRODUCT

Figure 3. Rock salt and trona ore.

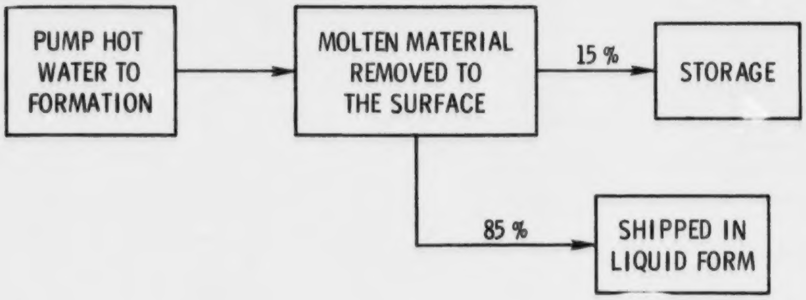
PUMP HOT WATER TO FORMATION
MOLTEN MATERIAL REMOVED TO THE SURFACE
15 %
STORAGE
85 %
SHIPPED IN LIQUID FORM

Figure 4. Sulfur (the Frasch hot water process).

Each mineral is described below in terms of annual production, composition, and unit operations to provide a broad perspective of the chemical and fertilizer mineral industry. A breakdown of population density and mineral production by state is presented in Table 2.

SOURCE TYPES

Barite (1-3)

Production--

U.S. production of barite in 1975 totaled 1,167,000 metric tons, a 16% increase over 1974 levels. Based on production figures for

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(1) Fulkerson, F. B. Barium. In: Mineral Facts and Problems. 1975 Edition. Preprint from Bureau of Mines Bulletin 667. U.S. Department of the Interior, Washington, D.C. 13 pp.

(2) Stevens, R. M. Barite. Mining Engineering, 29(3):53-54, 1977.

(3) Development Document for Effluent Limitations Guidelines and Standards of Performance, Mineral Mining and Processing Industry, Volume II, Minerals for the Chemical and Fertilizer Industries. Contract 68-01-2633, U.S. Environmental Protection Agency, Washington, D.C., January 1975. 310 pp.

TABLE 2. CHEMICAL AND FERTILIZER MINERALS PRODUCTION AND POPULATION DENSITIES BY STATE

State	Mineral	Production 10^3 metric tons	Population density, persons/km^2
Alabama	Brine salt	-[a]	30
Alaska	Barite	122	0.2
Arkansas	Barite	152	10
	Iron oxide pigments	-[b]	
California	Barite	10	10
	Borates	1,063	
	Lithium	-	
	Potassium salts	159	
	Evaporated salt	1,367	
	Sodium sulfate	1,118	
Colorado	Fluorspar	-	10
Florida	Phosphate rock	34,535	50
Georgia	Barite	-	30
	Iron oxide pigments	-	
Hawaii	Evaporated salt	-	50
Idaho	Phosphate rock	1,328	3
Illinois	Barite	-	80
	Fluorspar	60	
	Iron oxide pigments	-	
Kansas	Brine and rock salt	1,267	10
Kentucky	Fluorspar	-	30
Louisiana	Barite	-	30
	Brine and rock salt	11,929	
	Sulfur	3,019	
Michigan	Iron oxide pigments	-	60
	Brine and rock salt	4,370	
Missouri	Barite	178	30
Montana	Fluorspar	-	2
	Phosphate rock	1,328	
Nevada	Barite	498	2
	Fluorspar	-	
	Lithium	3	
	Evaporated salt	-	
New Jersey	Iron oxide pigments	-	370
New Mexico	Potash	1,837	3
	Evaporated and rock salt	132	
New York	Brine and rock salt	4,718	150
North Carolina	Lithium	9	120
	Phosphate rock	2,214	
North Dakota	Brine salt	-	3
Ohio	Brine and rock salt	4,224	100
Oklahoma	Evaporated salt	4.5	15
Pennsylvania	Iron oxide pigments	-	100
Tennessee	Barite	19	40
	Phosphate rock	2,214	
Texas	Barite	-	20
	Fluorspar	-	
	Brine and rock salt	9,391	
	Sodium sulfate	373	
	Sulfur	3,727	
Utah	Fluorspar	1	5
	Phosphate rock	1,328	
	Potash	272	
	Brine salt	650	
	Sodium sulfate	373	
Virginia	Iron oxide pigments	-	130
West Virginia	Rock salt	1,104	80
Wisconsin	Iron oxide pigments	-	30
Wyoming	Phosphate rock	1,328	1
	Trona ore	3,682	

[a] Dashes indicate data not available. [b] Estimated from current capacity.

the first 10 months, it appears that U.S. barite production in 1976 will increase by 5% over 1975. Nevada produced more than 70% of the 1975 output, followed by Missouri, Arkansas, Georgia, Alaska, California, Illinois, and Tennessee. A list of the principal producers and their geographical distribution is provided in Appendix A.

Source Composition--
Barite ($BaSO_4$) is the only source of barium and barium compounds. Theoretically, barite contains 65.7% barium monoxide (BaO) and 34.3% sulfur trioxide (SO_3). The chemical analysis of average barite ores is presented in Table 3 (4).

TABLE 3. CHEMICAL ANALYSIS OF AVERAGE BARITE ORE (4)

Component	Percent
Barium sulfate	94 to 96
Iron (III) oxide	0.8 to 2.0
Strontium sulfate	0.1 to 2.0
Barium carbonate	1.0
Silicon dioxide	3.0 to 6.0
Water	0.5 to 2.0
Fluorine	nil
Lead	nil
Zinc	nil

Most commercial sources are bedded deposits and vein deposits in limestone, dolomitic sandstone, and shale, or residual deposits in which chunks of barite are enclosed in clay. Barite sometimes occurs as a gangue mineral in metallic ores such as lead, zinc, and silver, and it is frequently associated with fluorspar.

Examples of replacement-type deposits occur in Arkansas, Nevada, and California. Residual deposits are found in Georgia, Missouri, Tennessee, and several eastern states.

Mining--
The barite industry uses a variety of mining methods depending on the size and type of deposit.

Bedded and vein deposits are mined by open pit or underground methods. In Nevada, barite in bedded deposits is blasted from open quarries with little or no subsequent sorting or beneficiation.

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(4) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Vol. 3. John Wiley & Sons, Inc., New York, New York, 1967. 927 pp.

Residual deposits of barite are usually mined by power shovels or dragline in open pits after removal of overburden. Overburden in Missouri is rarely over 0.6 m or 0.9 m, but in Georgia it may range from 3 m to 15 m. In most cases, the clay strata is hauled to the washing plant by dump trucks.

Beneficiation--
The methods used in the beneficiation of barite depend on the nature of the ore and the type of product to be made.

Of the significant U.S. locations producing either barite ore or ground barite, approximately 50% use log washing and jigging methods to prepare the ore for grinding. About 30% are dry grinding operations, and the remainder utilize froth flotation techniques for the beneficiation of the washed and/or jigged ore.

Wet process--Wet processing plants use washers or jigs to remove clay from the barite ore. The soft mined ore is passed through a breaker and fed to the log washer. The washed ore is then screened in a trommel circuit, dewatered, and finally jigged to separate gravel from the product. A flow diagram for wet processing is given in Figure 5.

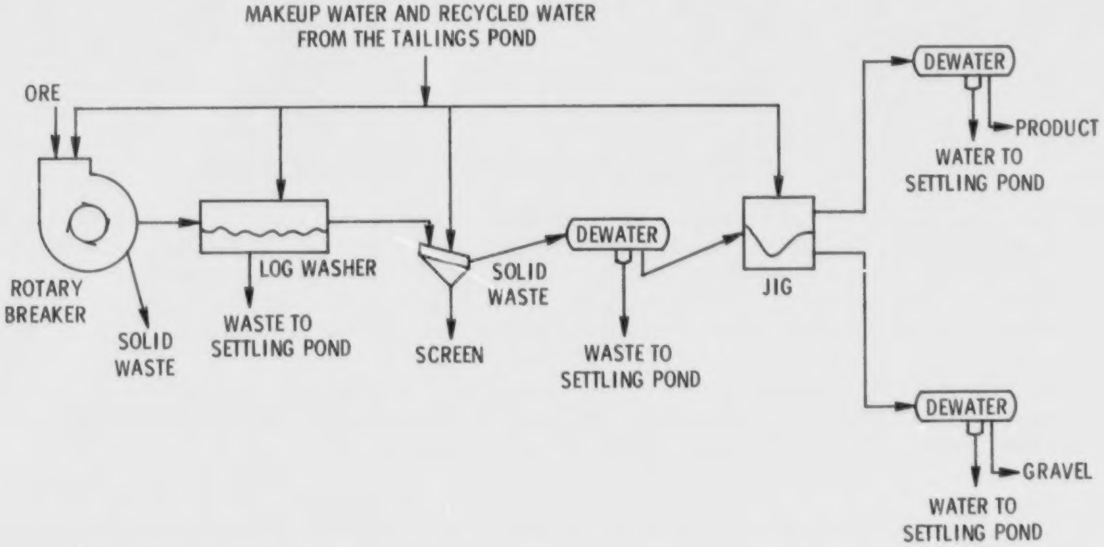
MAKEUP WATER AND RECYCLED WATER FROM THE TAILINGS POND
ORE
ROTARY BREAKER
SOLID WASTE
LOG WASHER
WASTE TO SETTLING POND
SCREEN
SOLID WASTE
DEWATER
WASTE TO SETTLING POND
JIG
DEWATER
PRODUCT
WATER TO SETTLING POND
DEWATER
GRAVEL
WATER TO SETTLING POND

Figure 5. Barite beneficiation (wet process).

Dry process--In dry grinding mills, the ore from stockpiles is batched in ore bins. At most locations the ore is soft, and crushing prior to the milling operation is unnecessary. Conveyor belts carry the ore from the bins to the mill for processing. If the ore is hard, it must be crushed before grinding to free barite from the gangue material. After the product is ground, it passes through a cyclone and a vibrating screen before being transferred into the product silos. The barite is removed from these silos either to bulk hopper cars or to the bagging plant. A flow diagram for dry processing of barite is given in Figure 6.

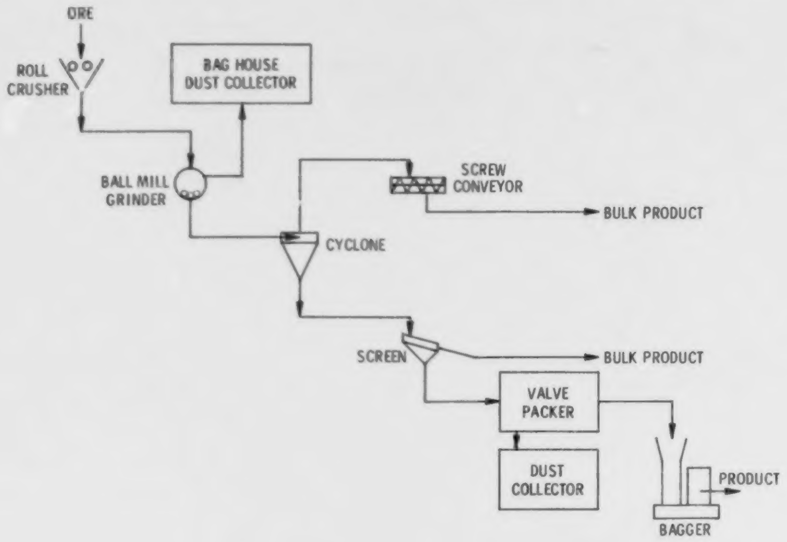
ORE
ROLL CRUSHER
BAG HOUSE DUST COLLECTOR
BALL MILL GRINDER
SCREW CONVEYOR
BULK PRODUCT
CYCLONE
SCREEN
BULK PRODUCT
VALVE PACKER
DUST COLLECTOR
PRODUCT
BAGGER

Figure 6. Barite beneficiation (dry grinding process).

Flotation Process--This process consists of crushing the ore to free it from gangue material, washing it to remove the clay, jigging the washed ore to separate the gravel, and grinding and beneficiating it by froth flotation to recover barite concentrates. The concentrates are filtered, dried, and bagged for shipment. A process flow diagram is given in Figure 7.

Borates (3, 5)

Production--

All U.S. boron production and about three-fifths of the world production comes from bedded deposits and lake brines in California. In 1975, U.S. production was recorded as 1,063,000 metric tons. A list of the principal producers and their geographical distribution is provided in Appendix A.

Source Composition--

The principal boron minerals (those of commercial value) are tincal ($Na_2B_4O_7 \cdot 10H_2O$), kernite ($Na_2B_4O_7 \cdot 4H_2O$), colemanite (borocalcite, $Ca_2B_6O_{11} \cdot 5H_2O$), ulexite (boronatrocalcite, $CaNaB_5O_9 \cdot 8H_2O$), priceite (pandermite, $5CaO \cdot 6B_2O_3 \cdot 9H_2O$), boracite (stassfurite, $Mg_7Cl_2B_{16}O_{30}$), and sassolite (natural boric acid, H_3BO_3).

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(5) Wang, K. P. Boron. In: Mineral Facts and Problems, 1975 Edition. Preprint from Bureau of Mines Bulletin 667, U.S. Department of the Interior, Washington, D.C. 12 pp.

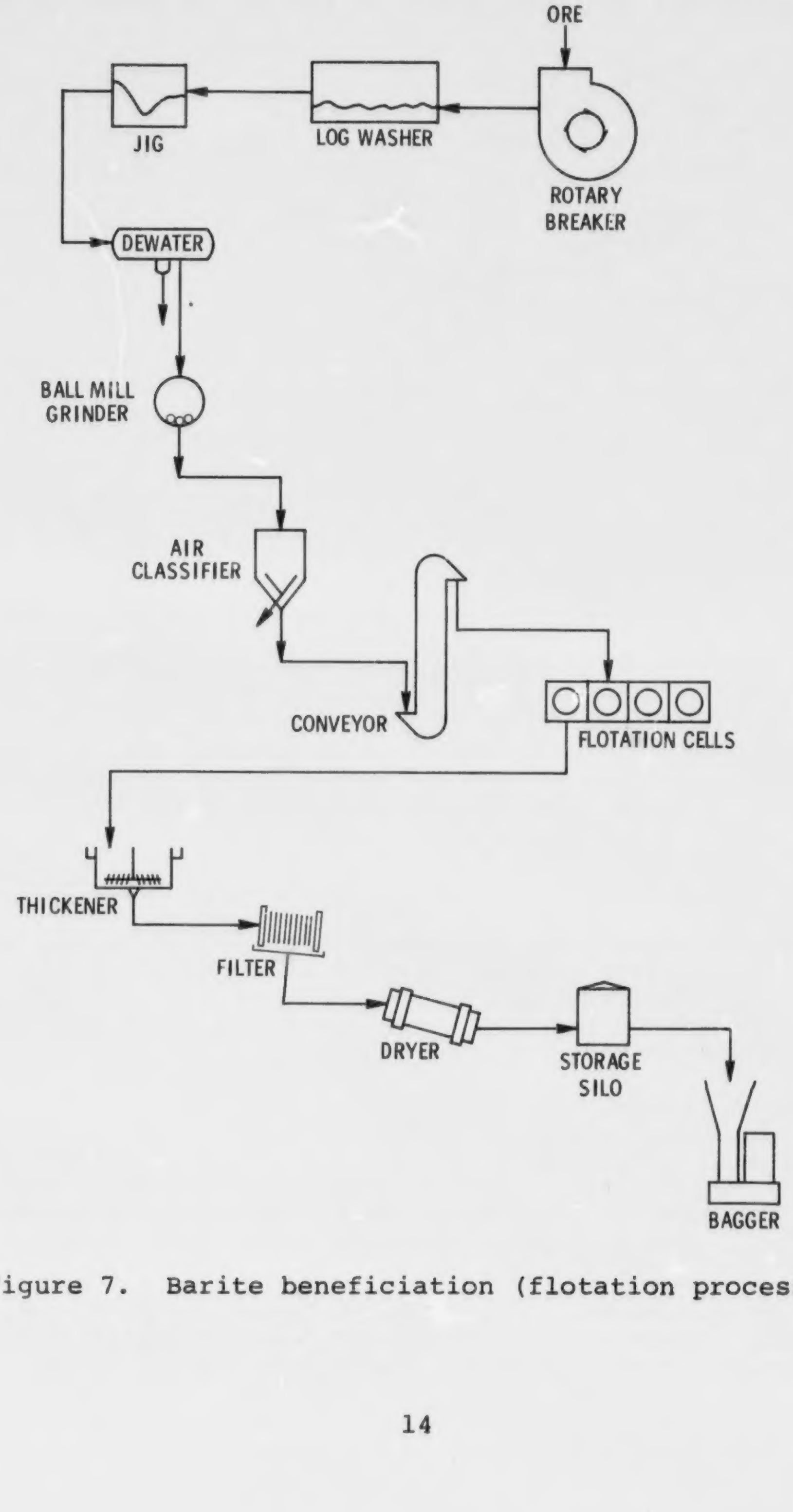
ORE
JIG
LOG WASHER
ROTARY BREAKER
DEWATER
BALL MILL GRINDER
AIR CLASSIFIER
CONVEYOR
FLOTATION CELLS
THICKENER
FILTER
DRYER
STORAGE SILO
BAGGER

Figure 7. Barite beneficiation (flotation process).

Virtually all the domestic reserve of boron minerals is in California. The primary deposit is at Boron; other deposits occur at Searles Lake and in the Furnace Creek district of Inyo County.

The large Kramer deposit at Boron is a high-grade, predominately crystalline tincal ore body overlying kernite. The overburden consists mainly of layers of shale, sandstone, conglomerate, and tufts of vegetation.

Mining and Beneficiation--

U.S. Borax and Chemical Corp., which accounts for over 75% of total U.S. borate production, mines its Kramer ore body at Boron by open pit methods. The pit is 305 m deep, and the ore is brought up by inclined conveyor. The crushed ore is shipped to a refining plant near the mine site for dissolving at about the boiling point of water, thickening, washing to remove impurities, and vacuum crystallization. A process flowsheet is provided in Figure 8.

Kerr-McGee employs the evaporative or "trona" process at its Trona Plant. (This plant was operated by American Potash and Chemical Corp. before the company was acquired by Kerr-McGee.) It has a daily boric anhydride (B_2O_3) capacity of 270 to 360 metric tons, including 136 metric tons of anhydrous borax and 72 metric tons of boric acid. It processes 0.63 m^3/s of brine pumped from a series of wells. A process flowsheet is provided in Figure 9 (4).

The Furnace Creek deposits contain both ulexite and colemanite. Tenneco Oil Co. owns the colemanite-ulexite open pits near Ryan which supply colemanite ore to a calcining plant near Death Valley Junction and ulexite to a mill at Dunn. After processing, the ores contain 26% to 28% B_2O_3.

Fluorspar (3, 6-8)

Production--

Domestic production of fluorspar in 1975 amounted to 111,000 metric tons. Most domestic fluorspar comes from Kentucky and Illinois, where four companies produced 85% of the acid and ceramic-grade fluorspar output. A list of the principal producers and their geographical distribution is presented in Appendix A.

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(6) MacMillan, R. T. Fluorine. In: Mineral Facts and Problems, 1970 Edition. U.S. Department of the Interior, Washington, D.C., 1973.

(7) Singleton, R. H. Fluorspar in 1975. Mineral Industry Surveys, U.S. Department of the Interior, Washington, D.C., November 17, 1976. 8 pp.

(8) Weisman, W. K. Fluorspar. Mining Engineering, 29(3):59-61, 1977.

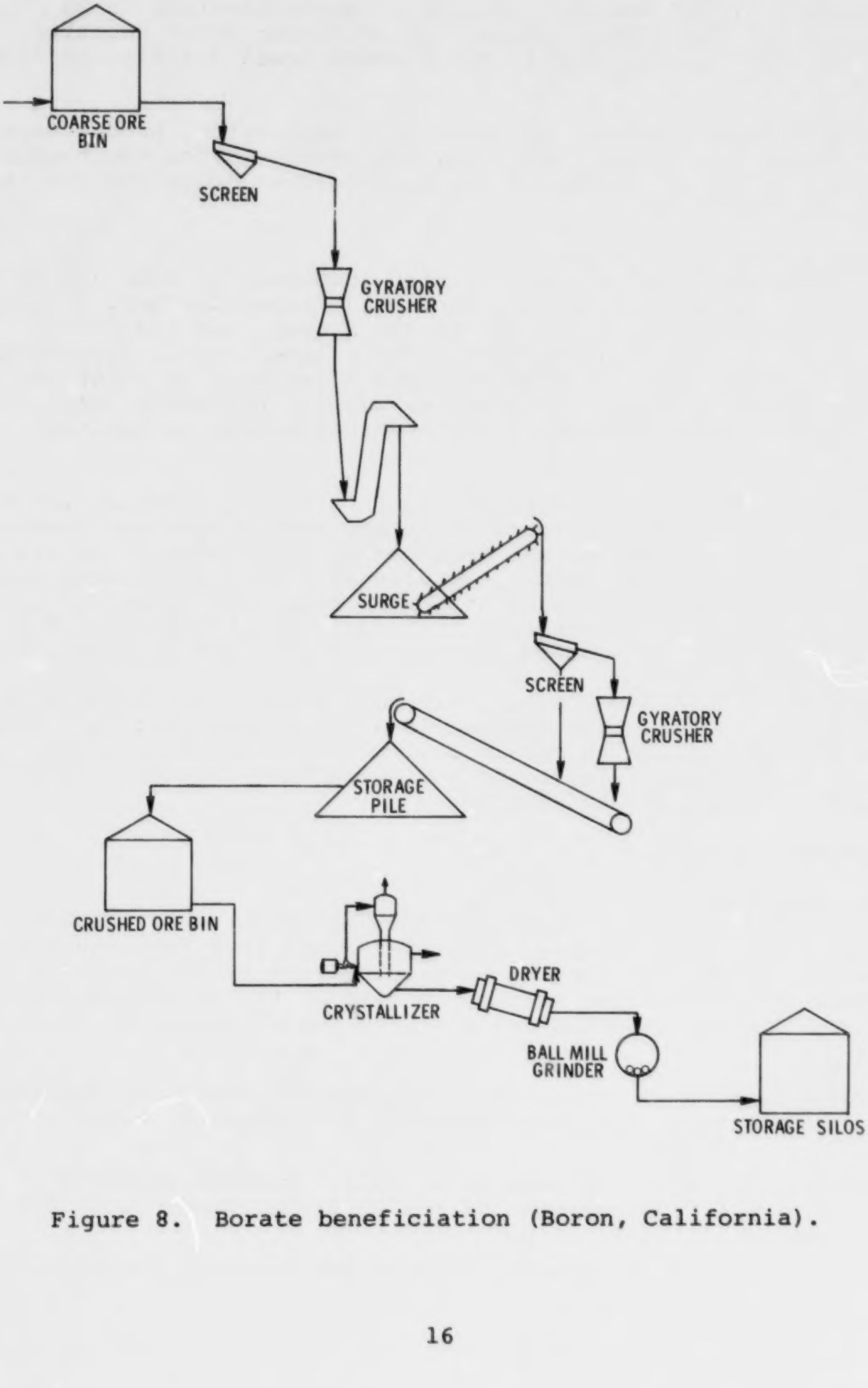
COARSE ORE BIN
SCREEN
GYRATORY CRUSHER
SURGE
SCREEN
GYRATORY CRUSHER
STORAGE PILE
CRUSHED ORE BIN
CRYSTALLIZER
DRYER
BALL MILL GRINDER
STORAGE SILOS

Figure 8. Borate beneficiation (Boron, California).

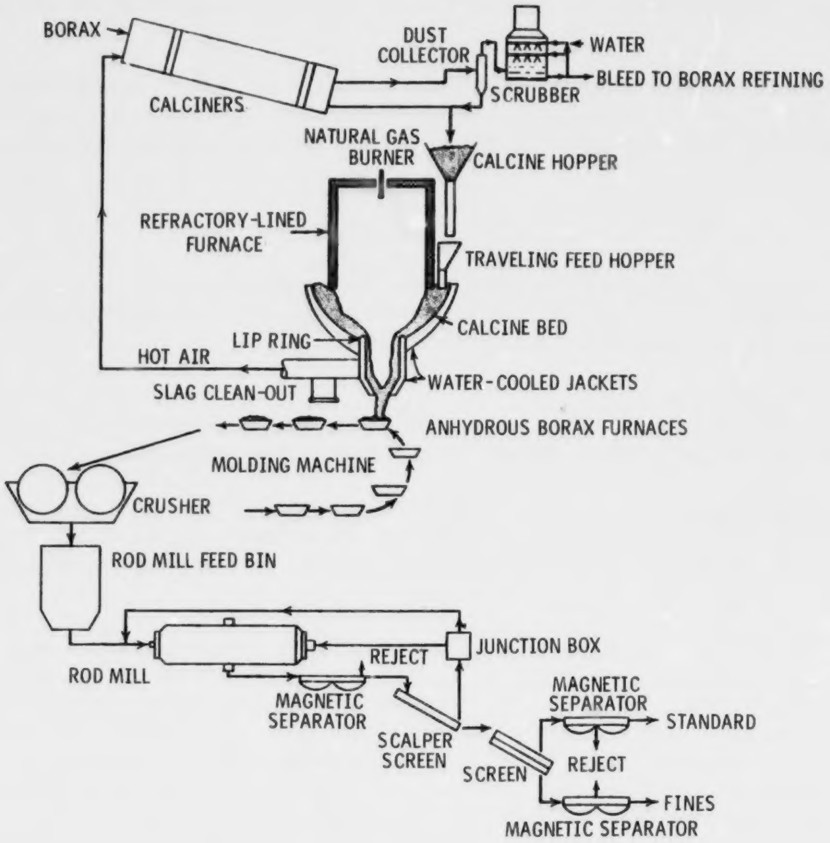
BORAX
CALCINERS
DUST COLLECTOR
SCRUBBER
WATER
BLEED TO BORAX REFINING
NATURAL GAS BURNER
CALCINE HOPPER
REFRACTORY-LINED FURNACE
TRAVELING FEED HOPPER
CALCINE BED
LIP RING
HOT AIR
SLAG CLEAN-OUT
WATER-COOLED JACKETS
ANHYDROUS BORAX FURNACES
MOLDING MACHINE
CRUSHER
ROD MILL FEED BIN
JUNCTION BOX
REJECT
ROD MILL
MAGNETIC SEPARATOR
SCALPER SCREEN
SCREEN
MAGNETIC SEPARATOR
STANDARD
REJECT
FINES
MAGNETIC SEPARATOR

Figure 9. Flowsheet for the production of anhydrous borax (standard fines) at Searles Lake, Trona, California, by Kerr-McGee Corp. (4).

Kirk-Othmer Encyclopedia of Chemical Technology, Copyright (c) 1967. Reprinted by permission of John Wiley & Sons, Inc.

Source Composition--
There are three generally recognized grades of fluorspar--metallurgical, ceramic, and acid. Metallurgical grades contain 60%, 70%, and 72.5% "effective calcium fluoride" (CaF_2). The "effective CaF_2" value is obtained by substracting 2.5 times the percentage of silica (SiO_2) from the percentage of CaF_2 in the ore or concentrate. For example, a concentrate of ore containing 85% CaF_2 and 5% SiO_2 is 72.5% effective CaF_2.

Ceramic grades range from 85% to 96% CaF_2, and the acid grade contains more than 97% CaF_2.

In the Illinois-Kentucky district, veins of fluorspar occur along faults in the country rock (limestone, shale, and sandstone).

Fluorspar veins vary in width from film thickness to more than 9 m wide.

In the western states, fluorspar occurs under a wide variety of conditions: as fillings forming more or less well-defined veins, in fractures and shear zones, and as replacements in the country rock.

Mining--

Mining is done by shafts, drifts, and open cuts. Mines range in size from small operations using mostly hand-operated equipment to large, fully mechanized mines.

Beneficiation--
The two main processes used to beneficiate fluorspar ore are wet heavy media separation (HMS) and froth flotation.

Heavy media separation--An HMS plant may not only upgrade and preconcentrate the ore to yield an enriched flotation feed, but it can also produce metallurgical grade gravel as a finished product.

The ore is first crushed to proper size, then washed and drained on vibrating screens to eliminate as much fines as possible. Oversize material is recycled back to the screen; undersize matter is sent to a spiral classifier for recovery as flotation plant feed. Middlings from the screening operation are fed to an HMS separatory cone which contains a suspension of finely ground ferro-silicon and/or magnetite in water, maintained at a predetermined specific gravity. The light fractions, or tailings, float and overflow a weir. The heavy particles (which are flotation feed) sink and are removed by an airlift.

The float and sink discharges go to drainage screens where 95% of the media are drained through the screens, magnetically separated from the slimes, and returned to the circuit.

The float and sink products pass over dewatering screens, and the water is pumped back to the plant. A flow diagram is provided in Figure 10.

Froth flotation--In froth flotation plants, fluorspar and other valuable minerals--barite, lead sulfide, and zinc sulfide--are recovered from the gangue material which is left as mill tailings. For the average small mill treating up to 90 metric tons of ore a day, primary crushing is adequate. Fluorspar ores usually require grinding to 48 mesh[a] or 65 mesh to liberate calcium fluoride from the gangue.

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[a] Mesh equivalents are given in standard engineering texts.

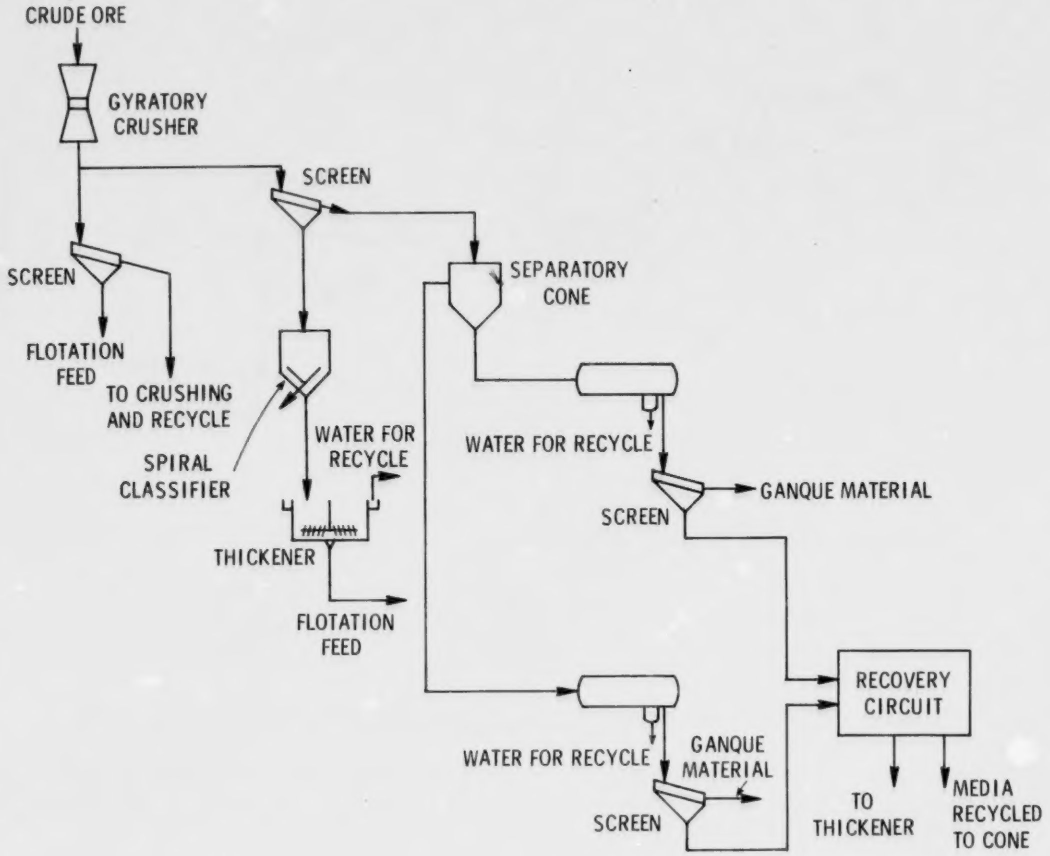
CRUDE ORE
GYRATORY CRUSHER
SCREEN
SCREEN
FLOTATION FEED
TO CRUSHING AND RECYCLE
SPIRAL CLASSIFIER
WATER FOR RECYCLE
THICKENER
FLOTATION FEED
SEPARATORY CONE
WATER FOR RECYCLE
GANQUE MATERIAL
SCREEN
RECOVERY CIRCUIT
WATER FOR RECYCLE
GANQUE MATERIAL
SCREEN
TO THICKENER
MEDIA RECYCLED TO CONE

Figure 10. Fluorspar beneficiation (HMS process).

Flotation of fluorspar must be extremely selective, especially when producing acid grade concentrate. The various grades of concentrates produced are stored in thickners until filtered.

The barite, lead sulfide, and zinc sulfide concentrates are sold in filter cake form. The fluorspar concentrates are dried in rotary kilns and then shipped. A flowsheet diagram for the froth flotation process is presented in Figure 11.

Lithium Minerals (9, 10)

Production--
In 1976, lithium chemicals were produced domestically by Foote

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(9) Cummings, A. M. Lithium. In: Mineral Facts and Problems, 1970 Edition. U.S. Department of the Interior, Washington, D.C., 1973.

(10) Alexander, J. H. Lithium. Mining Engineering, 29(3):66, 1977.

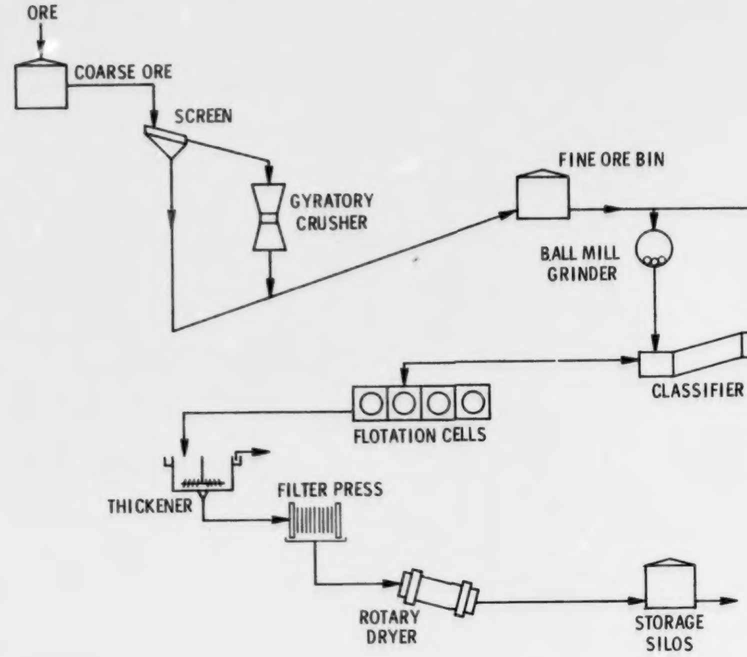
ORE
COARSE ORE
SCREEN
GYRATORY CRUSHER
FINE ORE BIN
BALL MILL GRINDER
CLASSIFIER
FLOTATION CELLS
THICKENER
FILTER PRESS
ROTARY DRYER
STORAGE SILOS

Figure 11. Fluorspar beneficiation (froth flotation).

Mineral Co., Lithium Corp. of America, and Kerr-McGee Corp. A list of principal producers and their geographical distribution is presented in Appendix A.

Mining--

Foote Mineral produces lithium chemicals from spodumene ore mined at Kings Mountain, North Carolina, and from lithium-containing brines at Silver Peak, Nevada.

Lithium Corp. of America has concentrated all of its lithium production at Bessemer City, North Carolina, where it mines spodumene from the pegmatite dikes.

Kerr-McGee continues to extract small quantities of lithium carbonate from the brines at Searles Lake, California.

Beneficiation--

In North Carolina, spodumene is recovered from the pegmatite ore by crushing, screening, grinding, and flotation. Lithium compounds are recovered from spodumene concentrates by acid or alkali treatment. See Figure 12 for a process flow diagram.

At the Searles Lake, California site, brine with a 0.033% lithium chloride (LiCl) content is concentrated in evaportors, causing several salts to precipitate. Through a combined leach-flotation process, the lithium compound is recovered as crystals. A

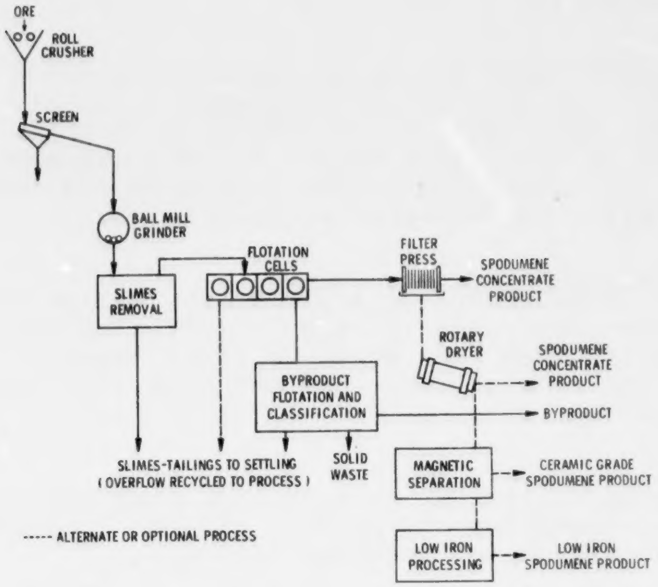
ORE
ROLL CRUSHER
SCREEN
BALL MILL GRINDER
SLIMES REMOVAL
FLOTATION CELLS
FILTER PRESS
SPODUMENE CONCENTRATE PRODUCT
ROTARY DRYER
SPODUMENE CONCENTRATE PRODUCT
BYPRODUCT FLOTATION AND CLASSIFICATION
BYPRODUCT
SLIMES-TAILINGS TO SETTLING (OVERFLOW RECYCLED TO PROCESS)
SOLID WASTE
MAGNETIC SEPARATION
CERAMIC GRADE SPODUMENE PRODUCT
LOW IRON PROCESSING
LOW IRON SPODUMENE PRODUCT
----- ALTERNATE OR OPTIONAL PROCESS

Figure 12. Spodumene beneficiation (flotation process).

process flowsheet is given in Figure 29 (Section 3). At Silver Peak, Nevada, brines containing 0.244% LiCl are concentrated to a 6% LiCl content by solar evaporation. A process flowsheet is presented in Figure 13.

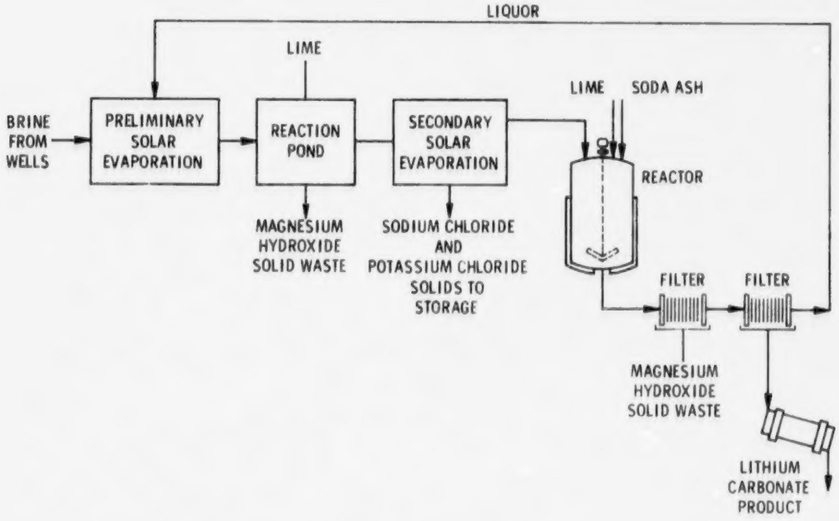
LIQUOR
LIME
BRINE FROM WELLS
PRELIMINARY SOLAR EVAPORATION
REACTION POND
SECONDARY SOLAR EVAPORATION
LIME
SODA ASH
REACTOR
MAGNESIUM HYDROXIDE SOLID WASTE
SODIUM CHLORIDE AND POTASSIUM CHLORIDE SOLIDS TO STORAGE
FILTER
FILTER
MAGNESIUM HYDROXIDE SOLID WASTE
LITHIUM CARBONATE PRODUCT

Figure 13. Lithium salt recovery (natural brine, Silver Peak operations).

Mineral Pigments (3)

Production--

Mineral pigments might better be called iron oxide pigments, since they are the only natural pigments currently being mined and processed. The quantity of natural iron oxide pigments sold by processors in the United States in 1972 was about 63,500 metric tons. A list of principal producers and their geographical distribution is presented in Appendix A.

Source Composition--

Hematite and limonite are minerals which consist mostly of iron oxides. Their occurrence is closely linked to that of iron ore. Pigment materials and iron ores are often mined in the same localities, and iron ores are used at times for red and brown mineral pigments.

Mining--

Iron oxide pigments are mined from open pits using power shovels or other earth removing equipment. At some locations, pigments are a minor byproduct of iron ore mining.

Beneficiation--

Two processes are used; the choice of process depends on the source and purity of the ore. For relatively pure ores, processing consists of crushing, grinding, and air classification. A drying step may also be included.

On the other hand, less pure ores require a washing step to remove sand and gravel, followed by dewatering and drying. These processes are presented in Figure 14.

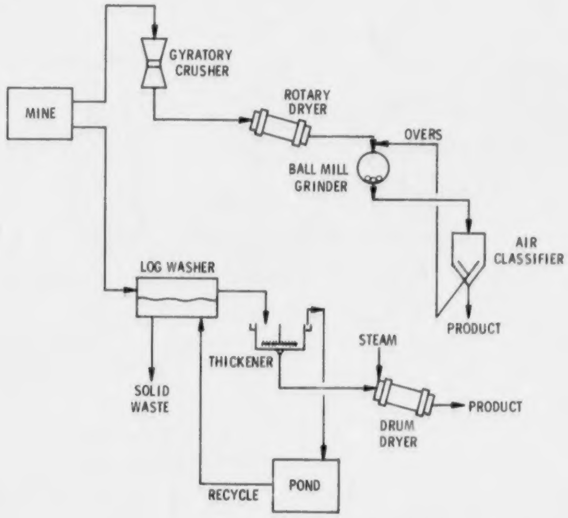
GYRATORY CRUSHER
MINE
ROTARY DRYER
OVERS
BALL MILL GRINDER
AIR CLASSIFIER
LOG WASHER
PRODUCT
STEAM
THICKENER
SOLID WASTE
PRODUCT
DRUM DRYER
POND
RECYCLE

Figure 14. Mineral pigment beneficiation.

Phosphate Rock (11, 12)

Production--

Production of phosphate rock in 1975 totaled 44,276,000 metric tons. Based upon U.S. Bureau of Mines figures, production for the first 10 months of 1976 was at a pace equal to 1975 figures. Phosphate is distributed in three major producing areas: Florida and North Carolina; the western states of Idaho, Montana, Utah and Wyoming; and Tennessee. Florida, by far the largest producer, provided over three quarters of the domestic production in 1975. A list of the principal producers and their geographical distribution is presented in Appendix A.

Source Composition--

Phosphate rock does not have an explicit chemical composition. The major phosphorus minerals of most phosphate rock are in the apatite group and may be represented by the formula $Ca_5(PO_4)_3(F, Cl, OH)$. The (F, Cl, OH) radical can be any combination of the fluoride, chloride, or hydroxyl ions, while the phosphate (PO_4) radical can be partly replaced by the vanadate, silicate, sulfate, or carbonate ions. Rare earths, chromium, cadmium, and uranium are other regular impurities. Uranium concentrations, which vary directly with the phosphate concentration of phosphate rock, usually are 40 to 165 g/metric ton of rock (13).

The Bone Valley Formation, an alluvial deposit east of Tampa, Florida, has become the most important phosphate resource in the United States. The Bone Valley material occurs in a matrix composed of clay, pebble phosphate, and sand in proportions of about one-third each. The matrix, ranging from 0.3 m to 15 m in thickness, averages about 5 m.

Research and development may convert the phosphate-bearing, Hawthorne Limestone Formation in Florida to an important phosphate reserve. The Hawthorne Limestone Formation is a dolomitic deposit underlying the land pebble deposits which has been exposed by present mining. The extent of the formation has not been fully determined, but it is estimated to contain several hundred billion metric tons of phosphate rock with an average grade of about 5% phosphorus pentoxide (P_2O_5), compared to the

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(11) Emigh, G. D. Phosphate Rock. Mining Engineering, 29(3):6870, 1977.

(12) Stowasser, W. F. Phosphate Rock. In: Mineral Facts and Problems, 1975 Edition. Preprint from Bureau of Mines Bulletin 667, U.S. Department of the Interior, Washington, D.C. 16 pp.

(13) Reconnaissance Study of Radiochemical Pollution from Phosphate Rock Mining and Milling. PB 241 242, U.S. Environmental Protection Agency, Denver, Colorado, December 1973. 106 pp.

11% to 14% of P_2O_5 ore now mined. The location of Florida phosphate deposits is provided in Figure 15 (14).

Mining--
Phosphate rock mining procedures are somewhat different in each of the major producing areas.

In Florida, the overburden covering the matrix is a quartz sand and clay averaging about 6 m in thickness. Electric-powered draglines strip the overburden and mine the matrix. The draglines work in cuts that may be 45 m to 80 m wide and range from approximately 300 m to 1000 m long. Overburden is stacked on natural ground level adjacent to the cut. The draglines deposit the matrix in previously prepared sluice pits. Hydraulic guns slurry the matrix, and it is pumped to the washing plant.

Mining procedure in North Carolina is similar to that in Florida.

In the western states, all phosphate ore is stripmined except that obtained from two underground mines in Montana. Ore mined in the western states is either truck-hauled or moved by rail to processing plants.

Ore in Tennessee is stripped and mined with small draglines and trucked directly to the plants or transferred to railroad cars for daily movement into the plants.

Beneficiation--
Beneficiation of eastern phosphate ore varies somewhat from plant to plant as grade, screen analysis, and ratio of pebble concentrate in the feed change. The matrix slurry (20% to 50% solids) is pumped through pipelines to the washing plant. Through a series of screens in closed circuit with hammer mills and log washers, the matrix is broken down to permit separation of the nonphosphate-bearing sand and clay from phosphate-bearing pebbles and sands. The separation is made at 14 mesh or 16 mesh to obtain a washed screen oversize pebble or coarse fraction.

The next step is the cyclonic removal of the -150 mesh material (slimes, colloidal clays, and very fine sands) which are pumped to settling ponds. The oversize phosphatic material is transferred to the flotation section, where it undergoes first stage flotation. The floated material may be stored or conditioned for a second stage flotation. The phosphate rock product is dried, sometimes ground, and stored in silos from which it is transferred to railroad hopper cars for transport. A process flowsheet is presented in Figure 16.

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(14) Bromwell, L. G. Dewatering and Stabilization of Waste Clays, Slimes, and Sludges. Florida Phosphatic Clays Research Project, Lakeland, Florida, June 1976. 43 pp.

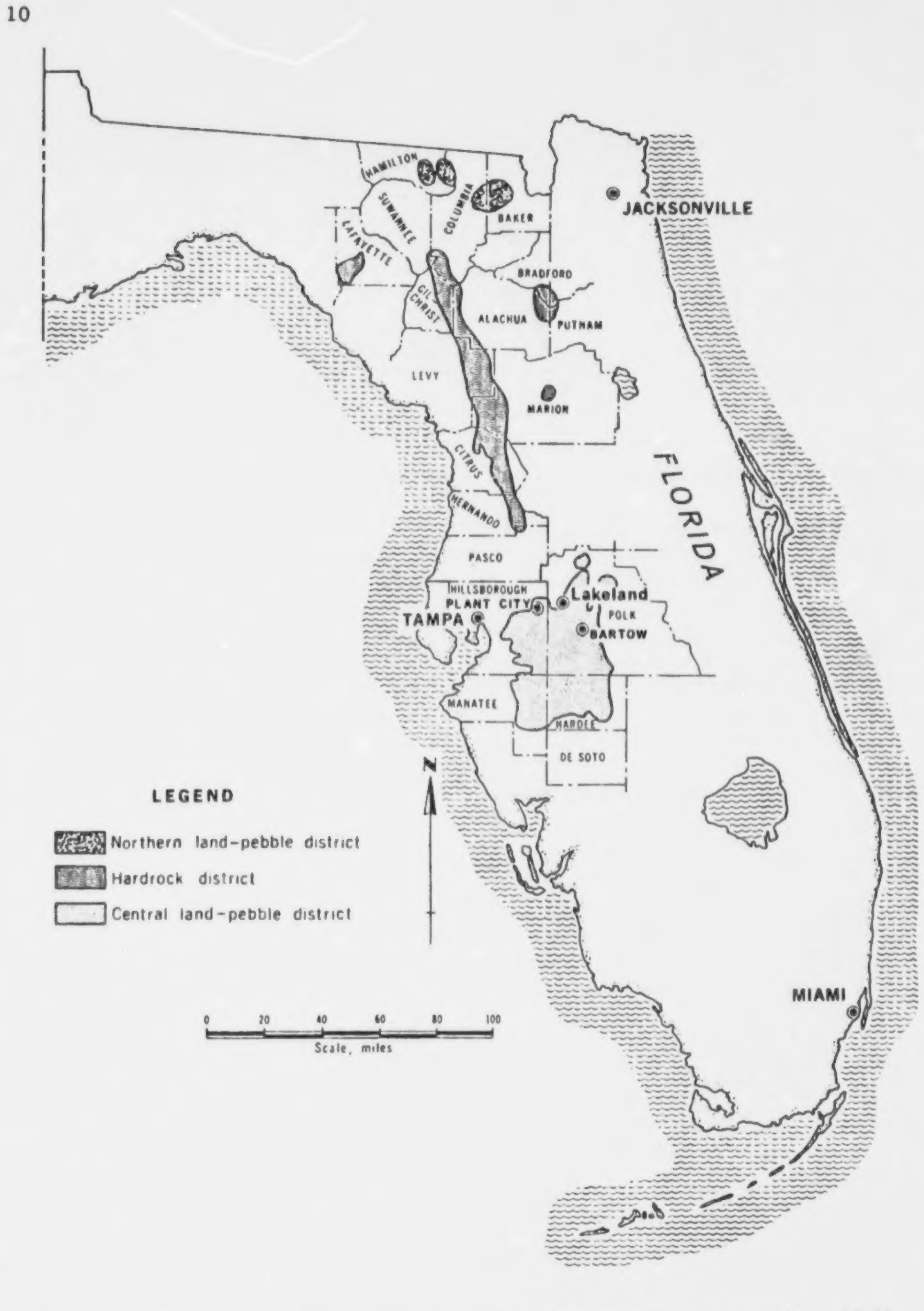
10
JACKSONVILLE
HAMILTON
SUWANNEE
COLUMBIA
BAKER
LAFAYETTE
GILCHRIST
BRADFORD
ALACHUA
PUTNAM
LEVY
MARION
CITRUS
HERNANDO
FLORIDA
PASCO
HILLSBOROUGH
PLANT CITY
Lakeland
TAMPA
POLK
BARTOW
MANATEE
HARDEE
DE SOTO
N
LEGEND
Northern land-pebble district
Hardrock district
Central land-pebble district
MIAMI
0
20
40
60
80
100
Scale, miles

Figure 15. Location of Florida phosphate deposits (14).

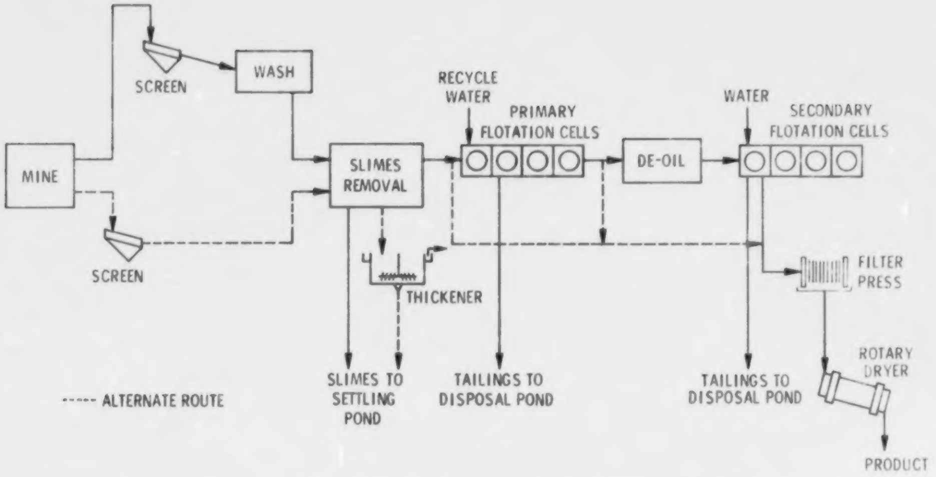
SCREEN
WASH
MINE
SCREEN
SLIMES REMOVAL
RECYCLE WATER
PRIMARY FLOTATION CELLS
DE-OIL
WATER
SECONDARY FLOTATION CELLS
THICKENER
FILTER PRESS
ROTARY DRYER
SLIMES TO SETTLING POND
TAILINGS TO DISPOSAL POND
TAILINGS TO DISPOSAL POND
PRODUCT
----- ALTERNATE ROUTE

Figure 16. Phosphate rock beneficiation (eastern process).

Western phosphate ore is transported from the mine to the plant by truck or rail. When it is beneficiated, it enters the first stage of beneficiation, which consists of crushing and/or scrubbing. Subsequent sizing is obtained by further crushing, grinding, and classification, with the sized feed being directed to the desliming section for removal of the -325 mesh material. The slimes are discharged either directly to a tailings pond or through a thickener. The underflow product from the desliming step is filtered, and it may be further processed through a drying and/or calcining step prior to shipment. A process flow diagram for western ore is given in Figure 17.

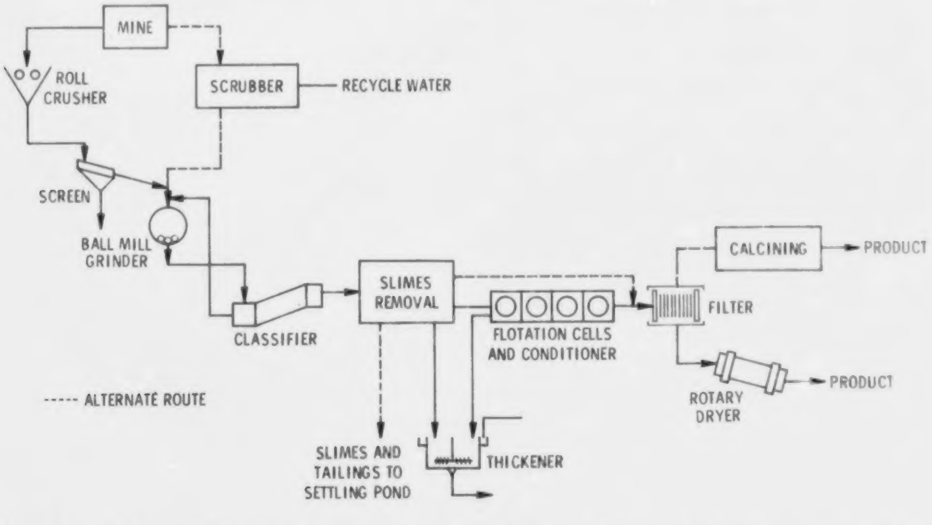
MINE
ROLL CRUSHER
SCRUBBER
RECYCLE WATER
SCREEN
BALL MILL GRINDER
CLASSIFIER
SLIMES REMOVAL
FLOTATION CELLS AND CONDITIONER
CALCINING
PRODUCT
FILTER
ROTARY DRYER
PRODUCT
----- ALTERNATE ROUTE
SLIMES AND TAILINGS TO SETTLING POND
THICKENER

Figure 17. Phosphate rock beneficiation (western process).

Potash (3, 15, 16)

Production--

In 1975, domestic production of potash totaled 2,268,000 metric tons of potassium oxide (K_2O). Preliminary estimates for 1976 production are 2,168,000 metric tons of K_2O.

The U.S. potash industry now comprises 10 firms which operate 11 facilities: 7 underground mines in New Mexico, 1 underground solution mine in Utah, 2 brine treatment plants in Utah, and 1 brine treatment plant in California. A list of the principal producers and their geographical distribution is presented in Appendix A.

Source Composition--

Potash is the common term for compounds of the element potassium, and it is often used to mean the equivalent K_2O content of substances, even though no oxide is actually present. Sylvinite, a mineralogical mixture of sylvite (KCl) and halite (NaCl), is the major ore for producing potash. A list of potash minerals is provided in Table 4 (17).

Currently 84% of domestic production comes from the bedded deposits in southeastern New Mexico near Carlsbad. A typical mineralogical analysis of New Mexico potash ore is presented in Table 5 (18). Average K_2O content of the New Mexico ore is 15%.

Mining--

Mining methods and equipment have been adapted from coal and salt mining. Shaft depths in New Mexico range from 233 m to 575 m.

Most of the mines in New Mexico use "conventional" mining methods: a cycle of undercutting, drilling, and blasting with an ammonium nitrate-fuel oil mixture, and a system of loaders, shuttle cars, and belt haulage.

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(15) Keyes, W. F. Potash. In: Mineral Facts and Problems, Bureau of Mines, 1975 Edition. Preprint from Bulletin 667, U.S. Department of the Interior, Washington, D.C. 15 pp.

(16) Rampacek, C. The Impact of R&D on the Utilization of Low-Grade Resources. Chemical Engineering Progress, 73(2):57-68, 1977.

(17) Katari, V., I. Gerald, and T. Devitt. Trace Pollutant Emissions from the Processing of Nonmetallic Ores. EPA-650/2-74-122, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, November 1974. 277 pp.

(18) Klingman, C. L. Salt. In: Mineral Facts and Problems, 1975 Edition. Preprint from Bureau of Mines Bulletin 667, U.S. Department of the Interior, Washington, D.C. 12 pp.

TABLE 4. POTASH MINERALS (17)

Type of ore	Minerological name	Composition	Equivalent K_2O content, %
Chlorides	Sylvite	KCl	63.1
	Carnallite	$KCl \cdot MgCl_2 \cdot 6H_2O$	17.0
Chloride-sulfates	Kainite	$MgSO_4 \cdot KCl \cdot 3H_2O$	18.9
Sulfates	Alunite	$K_2[Al(OH)_2(6)SO_4]_4$	11.4
	Polyhalite	$K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot 2H_2O$	15.5
	Langbeinite	$K_2SO_4 \cdot 2MgSO_4$	22.6
	Leonite	$K_2SO_4 \cdot MgSO_4 \cdot 4H_2O$	25.5
	Syngenite	$K_2SO_4 \cdot CaSO_4 \cdot H_2O$	28.8
	Krugite	$K_2SO_4 \cdot MgSO_4 \cdot 4CaSO_4 \cdot 2H_2O$	10.7
	Apthitalite	$(K,Na)_2SO_4$	42.5
	Picromerite	$K_2SO_4 \cdot MgSO_4 \cdot 6H_2O$	23.3
	Kalinite	$K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$	9.9
Nitrates	Niter	KNO_3	46.5
Silicates	Leucite	$KAl(SiO_3)_2$	21.4
	Feldspars:		
	Orthoclase	$KAlSi_3O_8$	16.8
	Anorthoclase	$(Na,K)AlSi_3O_8$	2.4 to 12.0
Micas	Muscovite	$H_2KAl_3(SiO_4)_3$	11.8
	Biotite	$(H,K)_2(Mg,Fe)_2Al_2(SiO_4)_3$	6.2 to 10.1
	Phogopite	$(H,K,Mg,F)_3Mg_3Al(SiO_4)_3$	7.8 to 10.3
	Lepidolite	$H,Li(Al,OH,F_2)Al(SiO_3)_3$	10.7 to 12.3
	Zinnwaldite	$H_2K_4Li_4Fe_3Al_8F_8Si_{14}O_{42}$	10.6
	Roscoelite	$H_8K(Mg,Fe)(Al,V)_4(SiO_3)_{12}$	7.6 to 10.3
	Glauconite	$KFeSi_2O_6 \cdot nH_2O$	2.3 to 8.5
	Carnotite	$K_2O \cdot 2U_2O_3 \cdot V_2O_5 \cdot 3H_2O$	10.3 to 11.2
	Nephelite	$K_2Na_6Al_8Si_9O_{34}$	0.8 to 7.1

TABLE 5. TYPICAL MINEROLOGICAL ANALYSIS OF POTASH ORE OF CARLSBAD, NEW MEXICO (17)

Component	Percentage (range)
Sylvite	23 to 28
Halite	71
Langbeinite	Trace to 2
Kainite	0.1 to 0.5
Leonite	Trace to 0.1
Kieserite	Trace to 1.0
Carnallite	Trace
Polyhalite	0.15
Anhydrite	Trace
Insolubles	0.5 to 1.5

Potash plants treating natural brines collect the brines by pumping from wells or collecting canals.

Beneficiation--

In New Mexico, the potash ore is usually processed in refineries adjacent to the mines. Two processes are employed: one for the recovery of potassium chloride (KCl) from sylvinite and the other for processing langbeinite ores.

Most of the KCl is recovered from sylvinite ore by flotation methods. The first step of this process is to treat the ore with a hydrophobic material (e.g., an aliphatic amine) which will selectively coat one of the ore constituents (KCl). Air is then bubbled through the slurry, and the air bubbles attach themselves to the coated particles and float them to the surface, while the uncoated particles sink. A process flowsheet is given in Figure 18. On a large scale and particularly with high-analysis ores, the flotation process is much cheaper than one involving dissolution and crystallization. However, available resources of the high-grade low-clay ores that have been mined and concentrated during the past 40 yr are declining in grade. The ore to be mined in the future is more difficult to beneficiate because its increased clay content interferes with flotation.

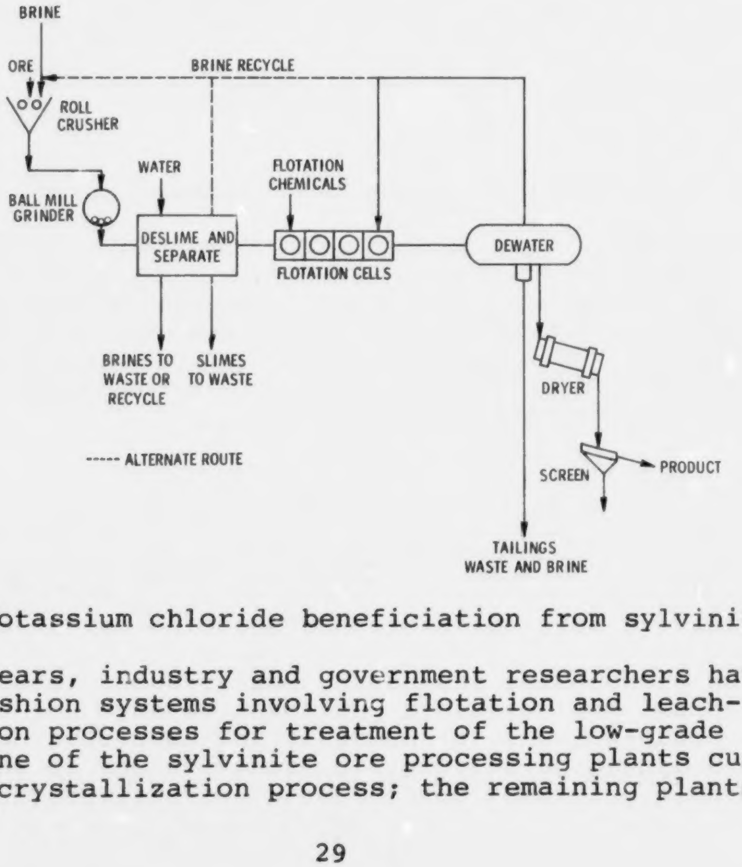
BRINE
ORE
BRINE RECYCLE
ROLL CRUSHER
WATER
FLOTATION CHEMICALS
BALL MILL GRINDER
DESLIME AND SEPARATE
FLOTATION CELLS
DEWATER
BRINES TO WASTE OR RECYCLE
SLIMES TO WASTE
DRYER
----- ALTERNATE ROUTE
SCREEN
PRODUCT
TAILINGS WASTE AND BRINE

Figure 18. Potassium chloride beneficiation from sylvinite ore.

For several years, industry and government researchers have been working to fashion systems involving flotation and leach-crystallization processes for treatment of the low-grade resources. One of the sylvinite ore processing plants currently uses a leach-crystallization process; the remaining plants use flotation.

Langbeinite is a natural potassium magnesium sulfate ($K_2Mg_2[SO_4]_3$) usually intermixed with sodium chloride. Two facilities at Carlsbad process langbeinite ore. The ore is mixed, crushed, and dissolved in water to which KCl is added. Partial evaporation of the solution produces selective precipitation of potassium sulfate (K_2SO_4), which is recovered by centrifugation or filtration from the brine liquor, dried, and sold. A simplified process flowsheet is given in Figure 19.

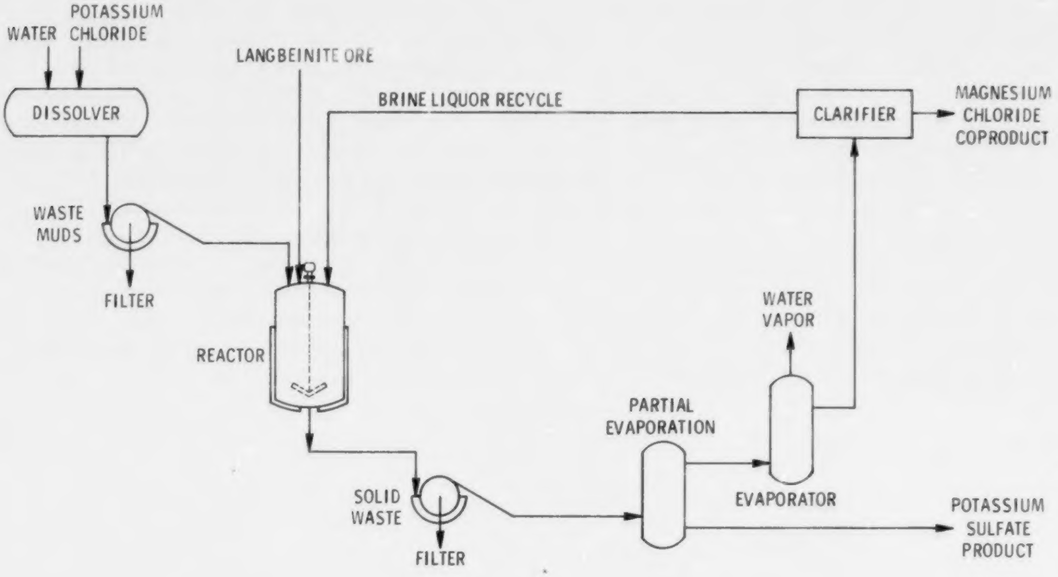
WATER
POTASSIUM CHLORIDE
LANGBEINITE ORE
DISSOLVER
BRINE LIQUOR RECYCLE
CLARIFIER
MAGNESIUM CHLORIDE COPRODUCT
WASTE MUDS
FILTER
REACTOR
WATER VAPOR
PARTIAL EVAPORATION
EVAPORATOR
SOLID WASTE
FILTER
POTASSIUM SULFATE PRODUCT

Figure 19. Langbeinite beneficiation.

In Utah, two facilities practice solution mining of sylvinite. A saturated brine is drawn to the surface and evaporated to dryness in large surface ponds. The dried material is then harvested from the ponds and separated by flotation into sodium and potassium chlorides. The sodium chloride tailings are discarded as waste; the potassium chloride is dried and packaged. A process flow diagram is provided in Figure 20.

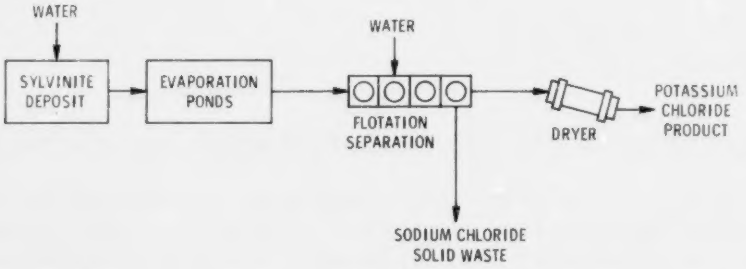
WATER
SYLVINITE DEPOSIT
EVAPORATION PONDS
WATER
FLOTATION SEPARATION
DRYER
POTASSIUM CHLORIDE PRODUCT
SODIUM CHLORIDE SOLID WASTE

Figure 20. Potash recovery by solution mining of sylvinite ore.

The processes employed at Searles Lake and at the Great Salt Lake are similar in that the brine is evaporated in steps to selectively recover sodium chloride, sodium sulfate, and potassium sulfate. Process flowsheets for mineral recovery from the Great Salt Lake and Searles Lake are provided in Figure 21 below and in Figure 29 in Section 3, respectively.

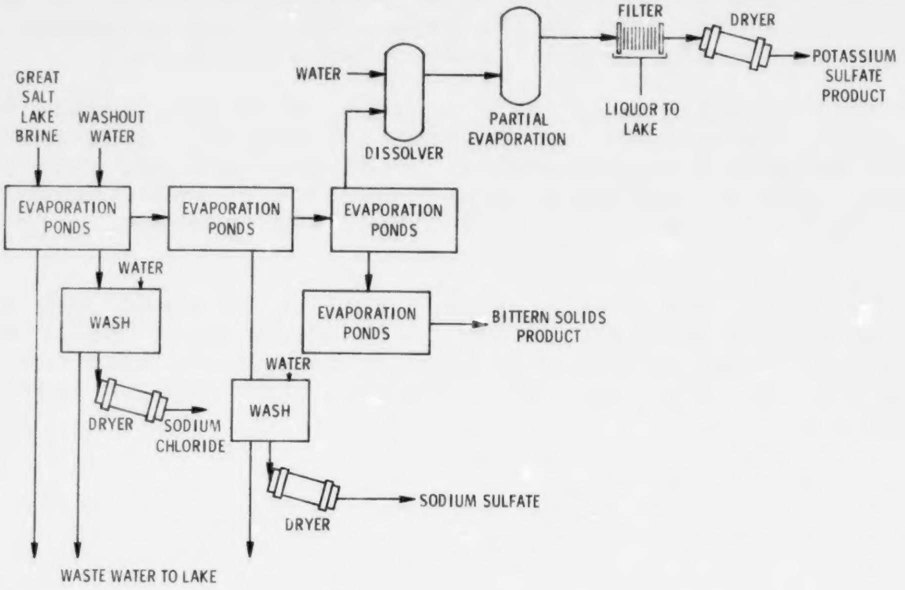
GREAT SALT LAKE BRINE
WASHOUT WATER
EVAPORATION PONDS
EVAPORATION PONDS
EVAPORATION PONDS
WATER
WASH
DRYER
SODIUM CHLORIDE
EVAPORATION PONDS
BITTERN SOLIDS PRODUCT
WATER
WASH
DRYER
SODIUM SULFATE
WASTE WATER TO LAKE
WATER
DISSOLVER
PARTIAL EVAPORATION
FILTER
LIQUOR TO LAKE
DRYER
POTASSIUM SULFATE PRODUCT

Figure 21. Minerals recovery at Great Salt Lake.

Salt from Brine, Rock Salt, and Evaporated Salt (3, 18)

Production--
Total salt production for the United States in 1976 was 38 million metric tons. Of the U.S. salt production, 55% was produced as salt in brine, 32% as rock salt, and 13% as evaporated salt. A list of the principal producers, types of operation, and geographical distribution of salt production is presented in Appendix A.

Source Composition--
Sodium chloride, or salt, is the chief source of all forms of sodium. Salt is produced on a large scale by mining bedded and dome-type underground deposits and by evaporating lake and sea brines.

Bedded deposits containing hundreds of feet of salt have been formed from ancient seas. Salt domes, such as those along the Texas-Louisiana coastline, are formed by geologic pressures which force bedded salt deposits to be extruded into vertical pipelike intrusions similar to volcanic necks. Salt domes have been drilled to a depth of 6,000 m without reaching the bottom of the salt.

Mining--

Over one-half of the U.S. salt output is produced by introducing water into a cavity in the salt deposits and removing the brine. Holes are drilled through the overburden into the deposit through a smaller pipe inside a casing. About 1 yr of pumping fresh water into a well is required to enlarge the cavity sufficiently to obtain full production of the saturated brine which forms in the cavity at the foot of the pipe. The brine is pumped or air-lifted through the annular space between the pipes.

Rock salt is mined on a large scale in Michigan, Texas, New York, Louisiana, Ohio, Utah, New Mexico, and Kansas. Room-and-pillar is the prinicpal mining method. Rock salt mining, like coal mining, uses conventional techniques such as undercutting, drilling, blasting, loading, transporting, and hoisting.

Beneficiation--

In most cases, the only treatment applied to mined rock salt is size reduction and classification by screening. One or more of the three stages of crushing occurs underground with the rest above ground. A process flowsheet for rock salt is provided in Figure 22.

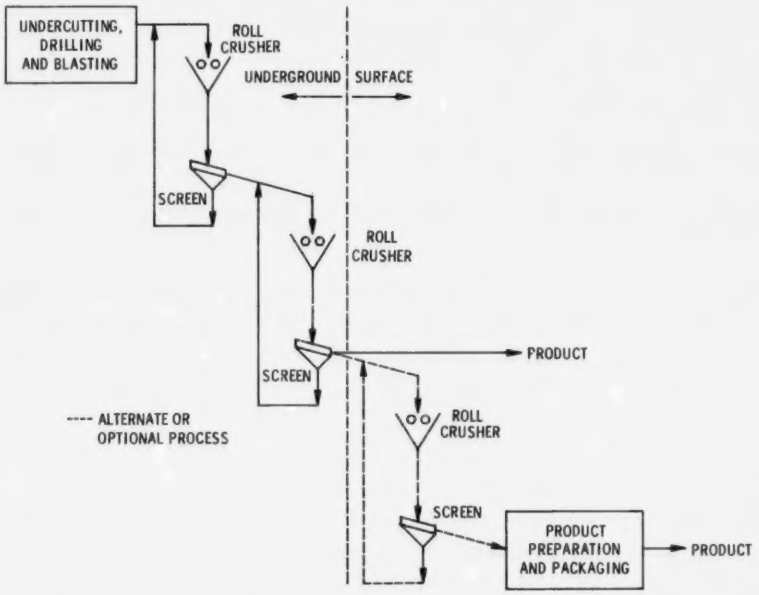
UNDERCUTTING, DRILLING AND BLASTING
ROLL CRUSHER
UNDERGROUND
SURFACE
SCREEN
ROLL CRUSHER
PRODUCT
SCREEN
---- ALTERNATE OR OPTIONAL PROCESS
ROLL CRUSHER
SCREEN
PRODUCT PREPARATION AND PACKAGING
PRODUCT

Figure 22. Rock salt mining and beneficiation.

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(19) Klingman, C. L. Soda Ash (Sodium Carbonate), Sodium Sulfate, and Sodium. In: Mineral Facts and Problems, 1975 Edition. Preprint from Bureau of Mines Bulletin 667, U.S. Department of the Interior, Washington, D.C. 13 pp.

Sodium Sulfate (3, 19)

Production--
U.S. production of sodium sulfate (Na_2SO_4), or salt cake, amounted to 1,184,000 metric tons in 1973. A list of the principal producers and their geographical distribution is presented in Appendix A.

Mining and Beneficiation--
Sodium sulfate is recovered from Great Salt Lake and Searles Lake brines by a step-wise evaporation process and from West Texas brines by a selective crystallization process. Process flow diagrams are shown in Figure 23 below and in Figure 29 in Section 3.

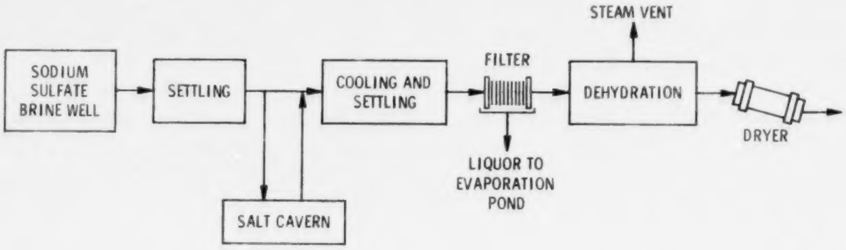

Figure 23. Sodium sulfate from brine wells.

Sulfur (3, 20, 21)

Production--
In 1975, the U.S. production of sulfur from Frasch mines was 7,325,000 metric tons. Frasch sulfur accounted for 64% of the domestic production of sulfur in all forms in 1975, as compared to 69% in 1974. Frasch sulfur was produced at 13 mines in Texas and Louisiana. A list of principal producers and their geographical distribution is provided in Appendix A.

Source Composition--
Native sulfur is sulfur that occurs in its elemental form in nature. Frasch sulfur is native sulfur mined by the Frasch hot-water process. Minable deposits of native sulfur are of three types: sulfur combined with anhydrite cap rock lying on salt domes, sulfur associated with bedded anhydrite, and sulfur at volcanic origin.

The major domestic sources of sulfur (85% of plant production) are associated with the Gulf Coast salt domes. The sulfur-

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(20) Shelton, J. E. Sulfur in 1975. Mineral Industry Surveys, U.S. Department of the Interior, Washington, D.C., July 10, 1976. 17 pp.

(21) Lewis, R. W. Sulfur. In: Mineral Facts and Problems, 1970 Edition. U.S. Department of the Interior, Washington, D.C., 1973.

bearing cap rock occurs at depths of less than 900 m as shown in Figure 24 (22). Most of the elemental sulfur is found in the limestone or carbonate zone of the cap rock, and it may vary from nearly 0 m to 100 m in thickness, having sulfur content which may range from traces to more than 40%.

Mining--

Mining of sulfur is accomplished by the Frasch, or hot water process, illustrated in Figure 25. In this process, sulfur is melted underground by pumping hot water to the formation. Molten sulfur is then raised to the surface through the drill pipe and stored as a liquid in steam-heated tanks. In most installations, the liquid sulfur is pumped directly into heated and insulated ships or barges which transport the sulfur in liquid form. Less than 15% of the total sulfur produced in the United States is metered and pumped to storage vats for cooling and solidifying before it is sold in dry form.

In addition to producing wells, "bleed-off" wells must be drilled in appropriate locations to control dome pressure and allow for continuous introduction of hot water (see Figure 24). A process flow diagram is provided in Figure 26.

Trona Ore (19)

Production--

In 1974, U.S. trona ore production was 3,682,000 metric tons. Most of the world's supply of natural soda ash comes from a small region in southwest Wyoming called the Green River Basin. A list of the principal producers and their geographical distribution is presented in Appendix A.

Source Composition--

The terms soda ash and sodium carbonate are used interchangeably. The material of commerce--trona--obtained from Wyoming normally contains more than 99.8% sodium carbonate, and the sodium chloride content is less than 0.05%. The presently mined deposits average 93% trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$), with small (less than 0.10%) quantities of sodium chloride and sodium sulfate.

Mining--

Underground mining of trona is similar to coal mining. Both room-and-pillar and longwall methods are used. The material is undercut, drilled, blasted, crushed, and transported to the surface by established methods.

Beneficiation--

The refining process for trona ore consists of its conversion to pure sodium carbonate. The process includes the removal of

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(22) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Vol. 19. John Wiley & Sons, Inc., New York, New York, 1967. 839 pp.

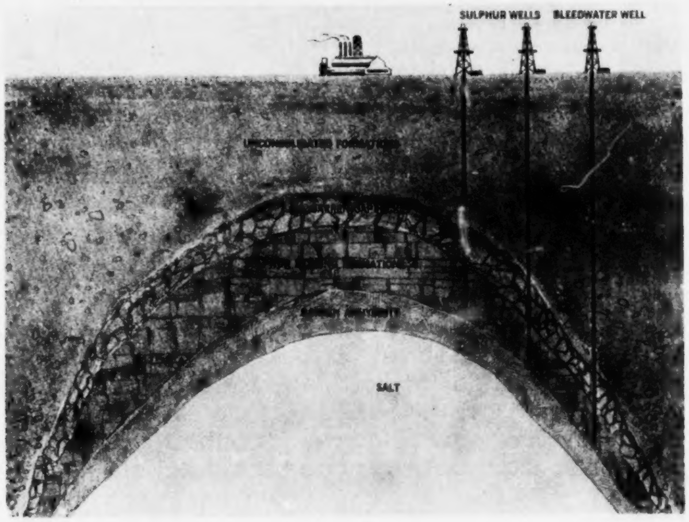
SULPHUR WELLS
BLEEDWATER WELL
UNCONSOLIDATED FORMATIONS
SALT

Figure 24. Cross section of a typical sulfur-bearing salt dome.

Kirk-Othmer Encyclopedia of Chemical Technology, Copyright (c) 1967.
Reprinted by permission of John Wiley & Sons, Inc.

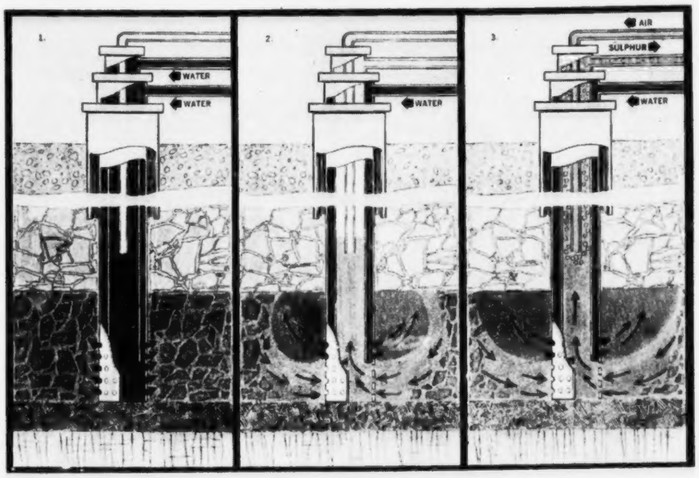
1.
WATER
WATER
2.
WATER
3.
AIR
SULPHUR
WATER

Figure 25. The Frasch process.

Kirk-Othmer Encyclopedia of Chemical Technology, Copyright (c) 1967.
Reprinted by permission of John Wiley & Sons, Inc.

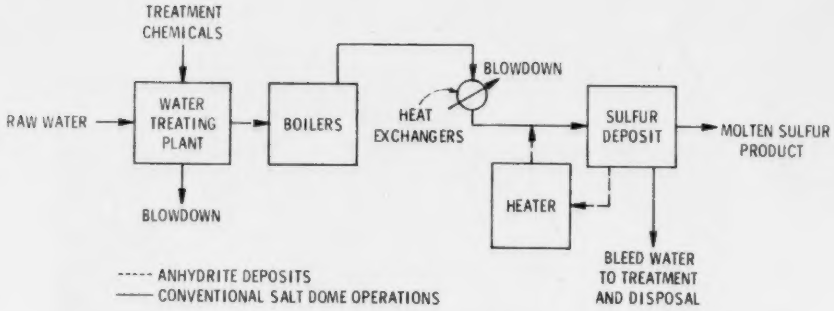
TREATMENT CHEMICALS
RAW WATER
WATER TREATING PLANT
BLOWDOWN
BOILERS
BLOWDOWN
HEAT EXCHANGERS
SULFUR DEPOSIT
MOLTEN SULFUR PRODUCT
HEATER
BLEED WATER TO TREATMENT AND DISPOSAL
----- ANHYDRITE DEPOSITS
—— CONVENTIONAL SALT DOME OPERATIONS

Figure 26. Sulfur mining and beneficiation.

insoluble impurities through crushing, dissolving and separation; removal of organic impurities through carbon absorption; and removal of excess carbon dioxide and water by calcining and drying to soda ash. Two variations of the process are used: the "sesquicarbonate" process and the "monohydrate" process. General process flowsheets for both processes are shown in Figures 27 and 28, respectively.

Searles Lake in California is the only U.S. source of natural soda ash other than the Green River Basin. The brines are obtained by drilling wells into the aquifer and installing pumps and pipelines to transfer the liquid to the processing plant. A process flowsheet is provided in Figure 29.

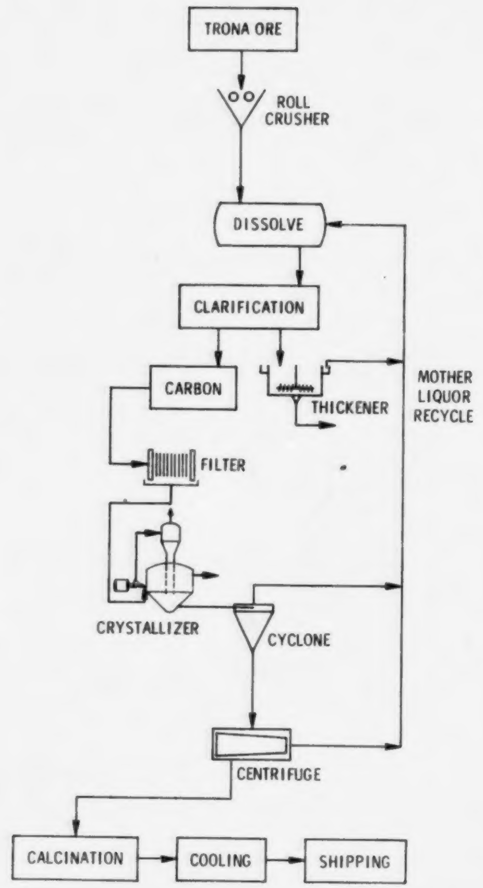
TRONA ORE
ROLL CRUSHER
DISSOLVE
CLARIFICATION
CARBON
THICKENER
MOTHER LIQUOR RECYCLE
FILTER
CRYSTALLIZER
CYCLONE
CENTRIFUGE
CALCINATION
COOLING
SHIPPING

Figure 27. Trona ore beneficiation (sodium sesquicarbonate process).

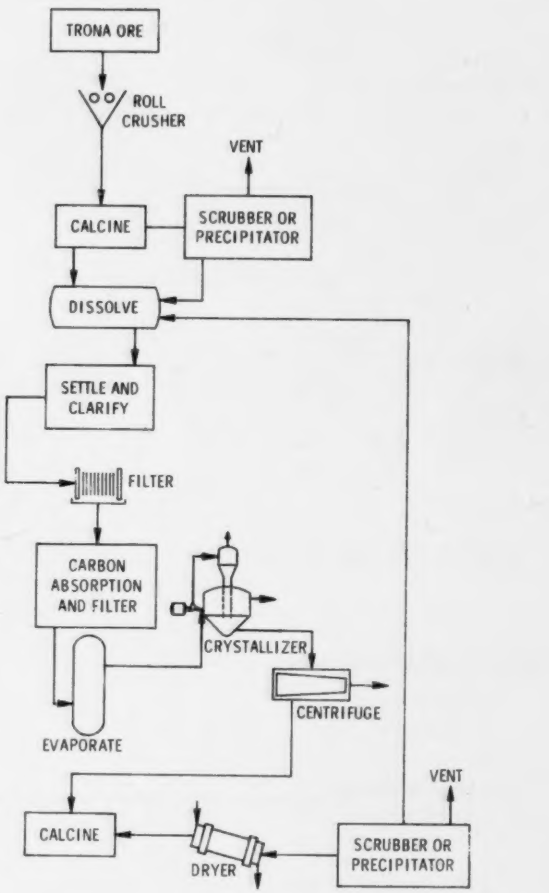
TRONA ORE
ROLL CRUSHER
VENT
CALCINE
SCRUBBER OR PRECIPITATOR
DISSOLVE
SETTLE AND CLARIFY
FILTER
CARBON ABSORPTION AND FILTER
CRYSTALLIZER
CENTRIFUGE
EVAPORATE
VENT
CALCINE
DRYER
SCRUBBER OR PRECIPITATOR

Figure 28. Trona ore beneficiation (monohydrate process).

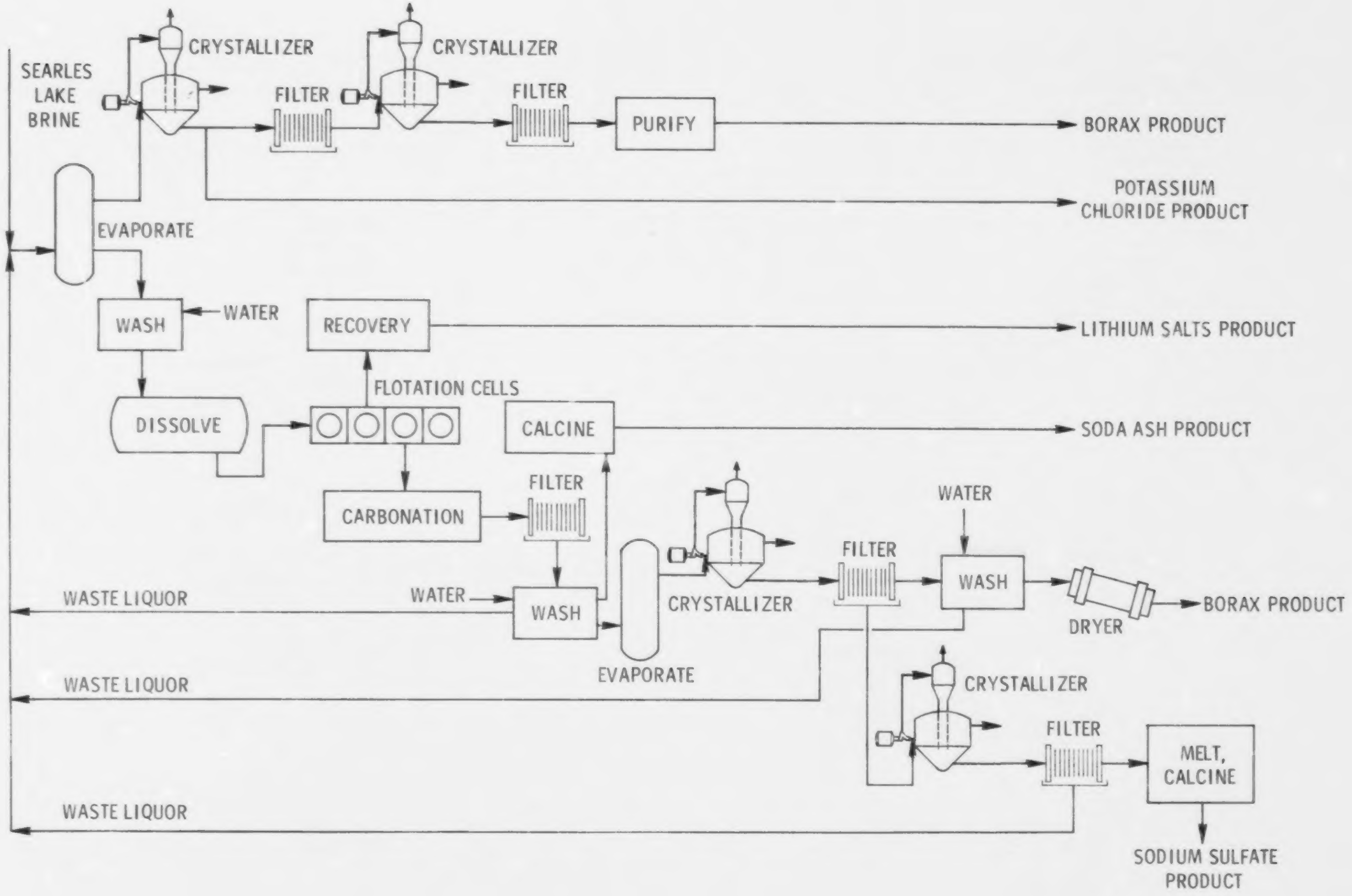
SEARLES
LAKE
BRINE
CRYSTALLIZER
FILTER
CRYSTALLIZER
FILTER
PURIFY
BORAX PRODUCT
POTASSIUM CHLORIDE PRODUCT
EVAPORATE
WASH
WATER
RECOVERY
LITHIUM SALTS PRODUCT
FLOTATION CELLS
DISSOLVE
CALCINE
SODA ASH PRODUCT
CARBONATION
FILTER
WATER
WASH
WASTE LIQUOR
EVAPORATE
CRYSTALLIZER
FILTER
WATER
WASH
DRYER
BORAX PRODUCT
WASTE LIQUOR
CRYSTALLIZER
FILTER
MELT, CALCINE
SODIUM SULFATE PRODUCT
WASTE LIQUOR

Figure 29. Searles Lake minerals recovery.

SECTION 4

EMISSIONS

SELECTED POLLUTANTS

The major air pollutant of concern emitted from the production of chemical and fertilizer minerals is respirable (less than 7-μm geometric mean diameter) particulate matter. This particulate contains free silica, the crystalline silicon dioxide which is mostly quartz, tridymite, and cristobalite.

The American Conference of Governmental Industrial Hygienists (ACGIH) has suggested a TLV® (threshold limit value) (23) for respirable particulates as shown in Equation 1:

$$\text{TLV} = \frac{10}{\%\ \text{quartz} + 2} \quad (\text{for } \%\ \text{quartz} \geq 1\%) \qquad (4)$$

where TLV = threshold limit value, mg/m^3
% quartz = percent of quartz in respirable dust

Respirable particulates with less than 1% quartz are termed "inert" and a TLV of 10 mg/m^3 is suggested for these (23). The criteria document on crystalline silica published by the National Institute of Occupational Safety and Health (NIOSH) states that occupational exposure shall be controlled so that no worker is exposed to a time-weighted average concentration of free silica greater than 50 $\mu g/m^3$ as determined by a full shift sample for up to a 10-hr workday, 40-hr workweek (23). In addition, particulate matter is one of the air quality criteria pollutants and has a 24-hr primary ambient air quality standard of 260 $\mu g/m^3$.

Nitrous oxides (NO_x) and carbon monoxide (CO) are emitted from blasting operations. These pollutants have threshold limit values of 9 mg/m^3 and 55 mg/m^3, respectively. Both of these are criteria pollutants with primary air quality standards of 100 g/m^3 (0.05 ppm) for the annual arithmetic mean for nitrogen dioxide (NO_2) and 10 mg/m^3 (9 ppm) for an 8-hr average concentration for CO. There is also a 1-hr average concentration standard for CO (35 ppm).

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(23) Documentation of Threshold Limit Values for Substances in Workroom Air. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1972. 97 pp.

EMISSION CHARACTERISTICS

Air Emissions

Air emission factors derived from direct sampling data are not available for most of the mineral producing industries in this study. In fact, the only direct information available concerns production of potash and phosphate rock.

Emission factors for respirable and total particulate emissions from the various mineral operations are presented in Table 6.

The major pollutant of each mineral industry in the study is respirable particulate matter. Because of this and the relative production figures, actual sampling was not deemed necessary for every mineral.

As can be observed from Table 6, phosphate rock alone accounts for 39% of the chemical and fertilizer mineral tonnage. Because phosphate rock production is so high in relation to the other minerals, additional air-sampling studies would have little utility in identifying potential problems of any proportion. Additional sampling would not be representative of the chemical and fertilizer mineral industry unless every mineral cited in this report was sampled.

In the absence of direct sampling data, estimates were determined by an indirect method (Appendix B).

Phosphate Rock--

Phosphate rock production accounts for an estimated 44% of the total particulate emission from chemical and fertilizer industry mining and beneficiation. The high percentage is caused by the large volume of phosphate rock production and the kinds of operations necessary to run an industry of its size. For example, the loading of railroad hopper cars, a major source of particulates, is an operation used only by industries with large amounts of material to handle.

The source of air emission during phosphate rock mining and processing are pictured in Figure 30. The emission factor which corresponds to each source and the following discussion are summarized in Table 7.

No sampling for the dragline source in Florida has been done. However, some estimates have been made on fugitive emission from other source assessment studies on mining. Dust emissions from surface mining of coal were measured by MRC as 0.085 g/kg of overburden removed. Battelle indicated that overburden removal was the largest emission source at strip mines and estimated 0.05 g/kg. Engineering Research and Technology, when providing input on the air quality aspects of coal development in northwest

TABLE 6. PRODUCTION AND PARTICULATE EMISSION DATA FOR THE CHEMICAL AND FERTILIZER MINERAL INDUSTRY

Mineral	Respirable particulate, g/metric ton	Total particulate, g/metric ton	Total particulate due to production, metric tons/yr	Contribution from production to overall national emission, %	Production: Tonnage, metric tons	Production: Year	Production: Percent of total
Barite	17	170[a]	198	0.001	1,167,000	1974	1.04
Borates	21	203[a]	216	0.001	1,063,000	1975	0.94
Fluorspar	36	350[a]	39	0.0002	111,000	1975	0.10
Lithium minerals	10	100[a]	1.2	0.000007	12,000[b]	1976	0.01
Mineral pigments	20	190[a]	12	0.0001	63,500	1972	0.06
Phosphate rock	37	362[c]	16,028	0.10	44,276,000	1975	39.29
Potash	110	1,110[c]	16,783	0.10	15,120,000[d]	1975	13.42
Brine salt	9	86[a]	1,797	0.01	20,900,000	1976	18.55
Rock salt	1.2	10[a]	122	0.0007	12,160,000	1976	10.79
Evaporated salt	9	86[a]	425	0.003	4,940,000	1976	4.38
Sodium sulfate	7.3	73[a]	136	0.001	1,864,000	1973	1.65
Sulfur	0.02	0.2[a]	1.5	0.000009	7,325,000	1975	6.50
Trona ore	11	110[a]	405	0.002	3,682,000	1974	3.27
Total			36,164	0.2	112,683,500		100

[a] Estimated. [b] Assumes 80% of current capacity. [c] Determined from sampling results. [d] Production for underground mines only.

TABLE 7. AIR EMISSION SOURCES OF PHOSPHATE ROCK MINING AND BENEFICIATION[a]

	Dragline: Stripping of overburden	Dragline: Mining of the ore	Drying	Silo storage	Loading	Total
Emission factor, g/kg	0.025	0.0004	0.071	0.105	0.161	0.362
Control devices:						
Existing types	None	None	Cyclone and wet scrubbers	Scrubbers	Enclosure	-[b]
Effectiveness, %	None	None	>95	>95	-[c]	-[b]
Future trends	None	None	None	None	Exhaust fugitive dust to control device	-[b]

[a] Numbers were derived from six sample runs made at one site. See Appendix H. [b] Not applicable.
[c] Not available.

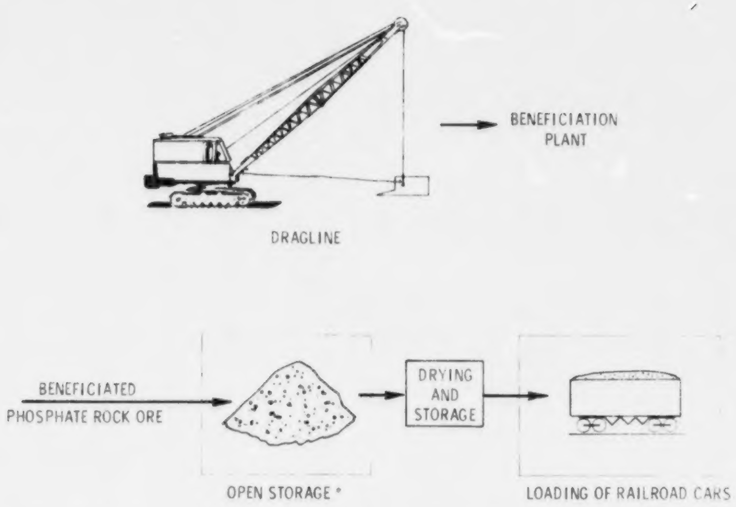

Figure 30. Selected phosphate rock sources.

Colorado, proposed an emission factor of 0.024 g/kg of overburden removal, including a correction for climatic conditions and control measures (watering) at the mines (24).

Overburden removal for phosphate rock mining is believed to be much less of a fugitive dust source than in coal mining because much less overburden material is handled; the average overburden depths in Florida are about 6 m versus up to 60 m for coal mining. Also, phosphate rock deposits in Florida are generally mined in areas where the water table is near the surface. Because the moisture content of the overburden is high, less dust is produced.

An emission factor for the overburden removal of phosphate rock lies toward the bottom of the range offered by PEDCo--0.024 g/kg to 0.05 g/kg of overburden (24). PEDCo estimated particulate emissions from dragline operations at an open pit copper mine in Butte, Montana. The emission rate of ore mined was 0.0004 g/kg. This excavation area was noted to be moist and nondusting. Although actual measurements were not taken at phosphate rock mines, an emission factor of this order of magnitude was felt to be representative for the mining of the ore.

After the overburden is removed, the ore is placed into sluice pits, broken up by hydraulic monitors, and subsequently pumped to the beneficiation plant. Each company's beneficiation methods differ slightly and are dependent on the characteristics of the matrix. In each case, however, the beneficiation is a wet process and therefore not a source of air emissions.

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(24) Evaluation of Fugitive Dust Emissions from Mining, Task 1, Report: Identification of Fugitive Dust Sources Associated with Mining. Contract 68-02-1221, Task 36, U.S. Environmental Protection Agency, Cincinnati, Ohio, April 1976. 78 pp.

The beneficiated rock is transferred to open storage piles. As this material is often moist, no controls are used or expected in the future although some emissions do result from the operations. The moist material is usually conveyed to a rotary dryer. A particle size distribution of phosphate rock dryer dust from one location is presented in Figure 31 (personal communication with H. Robert Trew, Agrico Chemical Co., Mulberry, Florida, February 17, 1977). An analysis of the particle emissions from phosphate rock processing and the results of MRC sampling and methodology are presented in Appendices G and H.

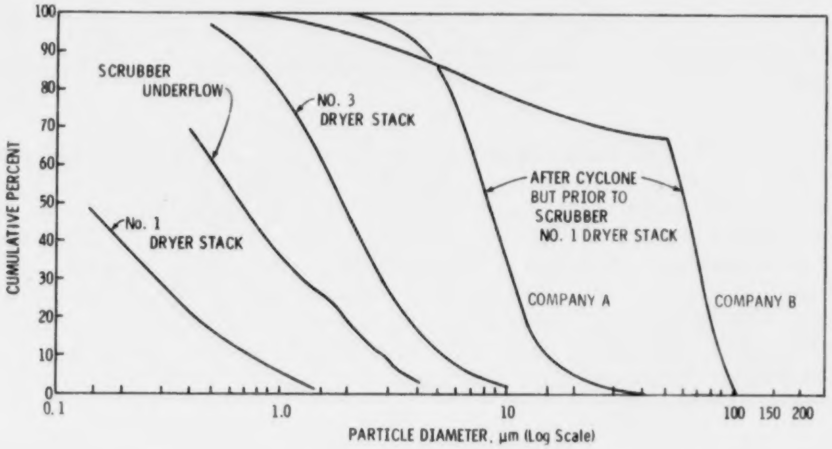

Figure 31. Particle size distribution of phosphate rock dryer dust.

Emission factors for phosphate mining that are presented in this report are based on Florida phosphate operations. Western phosphate mining operations are recognized as having greater air emissions because the rock is not generally wet-sluiced to beneficiation and dust may occur in transport from pit to processing plant. In addition, the overburden removal for western phosphate mining averages more than 6 m and is drier than the Florida overburden. For western mines, a more realistic overburden emission factor would be near the high end of the range or 0.05 g/kg of overburden (24). Thus for western mines, the overall emission factor could be about 7% greater than the factor for Florida mines.

Potash--

The air emission data for potash refinery activity near Carlsbad, New Mexico, is presented in Table 8 (15, 25). The seven

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(25) Nicholson, B. R. Air Quality Estimates of the New Mexico Potash Industry. State of New Mexico Environmental Protection Agency, Santa Fe, New Mexico, August 1976. 59 pp.

TABLF 8. NEW MEXICO POTASH PARTICULATE EMISSION DATA

Time basis: 31,536,000 s/yr

Company	Annual emission rate (25), g/s	Average K_2O content, %	Ore processed, 1975 production, kg/yr	Emission factor based on production, g/kg	Ore processed, current capacity (15), kg/yr	Emission factor based on capacity, g/kg	Comments
A	22.58	40	1.655×10^9	0.430	2.121×10^9	0.336	Dryer emissions only.
B	318.66	8	3.625×10^9	2.772	4.318×10^9	2.327	Includes a separate salt operation.
C	10.86	16	1.932×10^9	0.177	1.989×10^9	0.172	Uses a leaching operation.
D	62.82	18	1.944×10^9	1.019	2.778×10^9	0.713	-[a]
E	26.8	14	0.468×10^9	1.806	1.753×10^9	0.482	Dryer emissions only. Cutback due to construction
F	87.51	11	1.653×10^9	1.670	2.149×10^9	1.284	-[a]
G	91.97	23	2.202×10^9	1.318	2.273×10^9	1.334	-[a]

[a] Not applicable.

companies (A-G), which operate in the vicinity of Carlsbad, New Mexico, are listed. The two sets of emission factors, based on production and capacity, are presented to equalize any production irregulatities (such as E's cutback on production due to construction). A comments column is provided to explain the deviation among the numbers. Except where designated, the emission factors represent the total particulate emission of the refineries. These emission factors account for operations such as rock transfer, grinding, screening, drying, bagging, loading, and (in B and F's case) evaporation.

The major source of emissions is the drying operation, which is employed at all locations. The emission factors for A and E give a rough indication of the amount of emission caused by drying.

Another major source of particulate emission appears at the locations where langbeinite ore is processed by an evaporation step, using Ozark submerged-combustion evaporators. An Ozark evaporator consists of a tank to hold the liquid, a burner and gas distributor that can be lowered into the liquid, and a combustion-control system. Submerged-combustion evaporators often have a high entrainment loss. Prior particle size measurements of the particulate matter emitted from a plant's Ozark evaporator showed 100% of the particles to be less than 7 μm. These would all remain suspended. A study is currently in progress to assess the application of Monsanto's BRINK® fine particle eliminators to the problem.

State and National Emissions Burden--

Emission factors for total particulates were used to calculate each state's emission rate as the product of its emission factor and its mineral processing rate. The state emission burden is thus calculated as the percent contribution of the state's particulate emission rate for chemical and fertilizer mineral processing to its overall particulate emission rate. Appendix C displays the state emission burdens.

Water Effluents (3)

Most of the chemical and fertilizer mineral operations use large amounts of water and generate wastes in the form of overburden, slimes, and tailings.

Water used in the mineral mining and processing industry can be characterized as:

- Noncontact cooling water.
- Process water (wash water, transport water, scrubber water, process- and product-consumed water, and miscellaneous water).
- Auxiliary process water.

Noncontact cooling water is cooling water which does not come into direct contact with any raw material or product used in or resulting from the process.

Process water comes into direct contact with raw materials or products of the process.

Auxiliary process water is water which is used for process necessary in the manufacture of a product without contacting the process materials directly.

The amount of water used by facilities in the chemical and fertilizer mineral industry ranges from 0 to 726,400 m^3/day. Typically, the plants which utilize very large quantities of water use it for heavy media separation and flotation processes, wet scrubbing and noncontact cooling, or as the process medium in sulfur mining.

The following is a discussion of water uses and effluent characteristics for each mineral in the chemical and fertilizer mineral industry. Tables of effluent concentrations or mineral categories which have discharges are given in Appendix F.

Barite--

Mine water discharges--

Water use--Underground mine workings intercept numerous ground water sources. At one location, the water is directed from sumps in the mine to an upper level sump. The mine water is then neutralized with lime (CaO) for pH adjustment during pumping and sent to a pond for gravity settling prior to discharge into a nearby creek.

Effluent characteristics--The total annual effluent discharge to the creek is estimated to be 760,000 m^3/yr.

Wet process--

Water use--The quantity of water consumed, which ranges from 7.3 to 290 m^3 per metric ton of product at different sites, depends upon the quality of the ore and the type of waste material associated with the ore. Process water is recycled in all the plants; makeup water may be required at some.

Effluent characteristics--Under normal conditions, no effluent discharges from any of these plants. However, heavy rainfall, overflow from ponds can occur. The amount of such intermittent discharges is unknown.

Dry process--No water is used in barite dry grinding plants, nor is there any pumping of mine water.

Flotation process--

Water use--The plants in this category consume, on the average about 30.0 m^3 per metric ton of product. A large portion of the process water has been recycled from thickening operations. Well water and river water are used at some plants as additional process water.

Effluent characteristics--Barite plants have no or only intermittent discharges which occur during heavy rainfall or to maintain a constant pond elevation.

Borates--

Water use--The mined borax ore processing plant in the United States consumes 2.8 m^3/metric ton. An additional 0.8 m^3/metric ton enters with the ore. Most of the cooling water is recycled, and all the process wastewater is sent to evaporation ponds.

Effluent characteristics--There is no plant effluent.

Fluorspar--

Mine water discharge--Of the seven currently productive mines in the United States, six are underground and one is a dry open-pit mine. In addition, there are three underground mines being developed and five nonproducing mines which are active for mine dewatering purposes. At two of the productive mines, up to 40% and 62% of the mine discharge water is used at the mills. The remaining effluent is then discharged.

Heavy media separation--

Water use--In these plants, water consumption ranges from 2.7 to 9.6 m^3/metric ton of feed.

Effluent characteristics--Five of the six plants in this category have no effluent. The water is recycled back through closed circuit impoundments.

Froth flotation--

Water use--Ores with different physical characteristics require different quantities of process water. A maximum 20% of the process water is recycled from the thickeners, while the rest discharges into a ponding system. An average process hydraulic load for these plants is 2,070 m^3/day.

Effluent characteristics--Plant wastewater is treated in settling ponds. At most, 20% of the water from the clarification pond is recycled and the remainder is discharged. Total recycle attempts have failed because the numerous reagents used in various flotation circuits caused chemical buildups.

Lithium Minerals--

Natural brine (Silver Peak operations)--

Water use--Process water consists of brine from an underground source and fresh water used for wash purposes.

Effluent characteristics--All process water is evaporated. and there is no discharge.

Flotation process--

Water use--At both plants in this category, the process water recycle is 90% or greater. Total water usage is in the range of 13.0 to 28.0 m^3/metric ton of ore.

Effluent characteristics--Each plant has one effluent stream. The discharge consists primarily of settling pond overflow with minor contributions from mine pumpout and miscellaneous surface runoff.

Mineral Pigments--

Water use--At one plant, process water use is approximately 28.0 m^3/metric ton of product. The water is obtained untreated from a large settling pond. Approximately 95% of the process water overflows from the thickener and drains to the settling pond. The remaining 5% is evaporated on a drum dryer.

Effluent characteristics--The water effluent is sent to a settling pond from which there is no significant discharge.

Phosphate Rock--

Eastern process--

Water use--Nearly all water used in the beneficiation of phosphate ore is for processing purposes. Only small amounts are used for noncontact cooling and sanitary purposes. A typical hydraulic load is in the range of 41.0 m^3/metric ton of product.

Effluent characteristics--Effluents are periodically or continuously discharged from one or more settling areas by all of the beneficiation plants. The volume of effluent is related to:

- Percent recycle
- Amount of rainfall
- Surface runoff
- Available settling pond acreage

Western process--

Water use--The water used is almost totally for processing (greater than 95%) with only a small volume for other areas of the plant. An average water usage is 7.0 m^3 per metric ton of product.

Effluent characteristics--Most of the plants have no discharge.

Potash--

Water use--The average fresh water use at sylvinite and langbeinite ore plants is 4.0 and 7.0 m^3 per metric ton of product, respectively.

Fresh water use at the Utah operations amounts to 10,600 m^3/day. This water is used first on the flotation circuit and then in solution mining.

Effluent characteristics--There are no effluents from sylvinite or langbeinite plants. All wastewater streams are fed to evaporation ponds from which there are no discharges.

In Utah, the brine resulting from the operations is evaporated to recover solids for the flotation unit; there is no wastewater for discharge.

Salt from Brine, and Rock Salt--

Salt from brine (Great Salt Lake)--

Water use--Most wastewater comes from the washing of recovered sodium chloride.

Effluent characteristics--There are no effluents; discharged waste brines are returned to the lake source.

Rock salt--

Water use--In the mining and processing of rock salt, water consumption varies due to its miscellaneous uses. Water is routinely used for cooling, heating, and sanitation, with a small volume used to dissolve anti-caking reagents. Variable amounts are also used in dust collection and washdown of waste salt. The volume of intake water per unit of production can range from 0.01 to 1.3 m^3 per metric ton of product.

Effluent characteristics--Plant effluents consist primarily of mine seepage and wastewater from dust collectors and miscellaneous washdown of operating areas.

Sodium Sulfate--

Water use--Process water consists entirely of brine, all of which goes to the process and then to waste with no recycle.

Effluent characteristics--There is no discharge at these locations; in the arid climate, effluents evaporate.

Sulfur--

Anhydrite deposits--

Water use--Plants located on anhydrite deposits consume about 8.0 m^3 of water per metric ton of product. Approximately 50% of the water is recycled back to the system, and the remainder is lost in the sulfur-bearing formation.

Effluent characteristics--There is no process water effluent from these plants.

Salt dome operations--

Water use--The average amount of process water consumed by each of the plants is about 30,000 m^3/day. These plants are all designed for a given hot water load. The sulfur-to-water ratio varies a great deal from formation to formation, and the quantity of water used by the industry is not determined solely by the quantity of product.

Effluent characteristics--The major waste from salt dome mines is the bleedwater from the formation.

Trona Ore--

Water use--Water use at mines with attached refineries is determined principally by the refining process. The only kinds of water intrinsically associated with the mines are mine pumpout water, dust control water, and sanitary water, the latter two being rather small.

Most plant water intake comes from the Green River (fresh water) and from mine pumpout (salt water). In some instances, mine pumpout is used as part of the process water; in others, it is discharged to the treatment ponds. The average river intake for three refiners is 8,700 m^3/day; average pumpout for all four trona ore mining facilities is 640 m^3/day.

There are three major routes of consumption:

- Evaporation by drying operations and cooling water recycling.

- Discharge of wastewater to evaporation ponds.

- Discharge of wastes to waterways.

Effluent characteristics--Only one facility discharges process wastewater, and plans are under way to eliminate this.

One mining plant discharges its mine water; another plant discharges ground and runoff waters.

DEFINITION OF THE REPRESENTATIVE SOURCE

A Florida phosphate rock-producing facility was chosen as representative of the chemical and fertilizer mineral industry because:

- Phosphate rock constitutes 40% of the chemical and fertilizer mineral output.

- The bulk of the industry is concentrated in a relatively small area (about 3 1/2% of Florida's land area, and the plants have large capacities.

- The unit operations used by the phosphate rock industry are representative of the whole chemical and fertilizer mineral industry.

The representative source is defined as one with average emission parameters; i.e., average emission factor and average production rate. Florida phosphate rock plants have production rates of from 450,000 metric tons/yr to 4,500,000 metric tons/yr with an average of 2,000,000 metric tons/yr.

The average emission factor was determined by making six sample runs at one site (Appendix H). Thus the representative source has an emission factor of 0.037 g/kg for respirable particulates.

The sampled plant had an average area of 0.51 km^2. The representative distance to plant boundaries, taken as the radius of a circle whose area is equal to the area of the plant, was 400 m. The representative population density was taken as the population density of Polk County, Florida, the major producing area, and was determined to be 50 persons/km^2.

HAZARD RATIO

Air

The maximum hazard ratio due to respirable particulate emissions from the representative plants of each mineral category is provided in Table 9. An example of hazard ratio calculations is provided in Appendix E, together with the equations utilized.

TABLE 9. HAZARD RATIO CALCULATIONS

Mineral	Number of principal sites	Representative plant size, metric tons/yr	Emission rate of respirable particulate, g/s	Representative distance to plant boundary, m	Hazard ratio for respirable particulates	Average population density of major producing areas, persons/km^2	Affected population, $0.1<S_p<1.0$ persons
Barite	24	50,000	0.05[a]	400	0.004	10	0
Borates	3	800,000	0.90[a]	400	0.07	10	0
Fluorspar	11	10,000	0.02[a]	400	0.002	80	0
Lithium	4	3,000	0.002[a]	400	0.0002	120	0
Mineral pigments (Iron oxide pigments)	15	4,000	0.004[a]	400	0.003	100	0
Phosphate rock	23	2,000,000	4.0[b]	400	0.3	50	15
Potash	7[c]	2,000,000	12.0[b]	400	0.9	3	15
Brine salt	37	600,000	0.30[a]	400	0.02	50	0
Rock salt	19	600,000	0.04[a]	400	0.003	10	0
Evaporated salt	11	450,000	0.20[a]	400	0.02	20	0
Sodium sulfate	5	400,000	0.20[a]	400	0.02	10	0
Sulfur	13	600,000	0.0006[a]	400	0.00005	30	0
Trona ore	3	1,000,000	0.60[a]	400	0.05	1	0
Total	170						

[a] Estimated. [b] Determined from sampling results. [c] Includes only New Mexico mines.

Water

The phosphate rock industry was the only one for which complete information was available concerning river flow rate and concentration. For a representative source discharging into Florida's Peace River, the hazard ratios of elemental phosphorus, fluoride, and total suspended solids are 0.061, 0.051, and 0.0025, respectively. Hazard ratio calculations are provided in Appendix E, together with the equations utilized.

SECTION 5

CONTROL TECHNOLOGY

STATE OF THE ART--AIR POLLUTION CONTROL TECHNOLOGY

Phosphate rock

Since the stripping of overburden and mining of the Florida phosphate matrix is carried out under somewhat "wet" conditions, industry does not consider this a source of air emissions. Therefore, they have no controls on this operation and do not expect a future need. Since this condition is naturally different for the western operations, controls may be needed.

The beneficiated rock in open storage piles is moist. No controls are used or expected in the future, although some emissions do result.

Typically, the moist material is conveyed by an underground belt operation to a rotary dryer. The dust from the dryers is handled by cyclone-wet scrubber combinations. (One operation uses a rotary dryer which has a cyclone scrubber followed by twin wet scrubbers.) In this way, the emission becomes a stack emission. Collection efficiencies of this control device are greater than 95%, and no further controls are expected in the future. At this point, the material may be ground, sometimes under wet conditions; the procedure varies from plant to plant. One plant which was visited does not use a grinding operation at all.

The material is transferred from the dryer to storage silos. Control devices on rock transfer junctions are typically scrubbers, with an average collection efficiency greater than 95%. From the storage silos the rock is dropped into railroad hopper cars for transportation to fertilizer manufacturing centers. In loading facilities typical of the phosphate industry, loading is accomplished manually from overhead storage by an operator standing at the roof level of the railroad car. Usually the drop areas have flexible rubber couplings which deliver the rock to within about 0.610 m (2 ft) of the top of the loading door; this helps direct the rock. However, the loading problem is not dusting caused by the drop, but the pickup of dust in the displaced air from the railroad car. The industry is working to control the dust in this operation.

Companies have installed extensive ductwork systems to capture the dust and exhaust it to a scrubber. However, as noted by one industry representative, operators do not always use the equipment properly. Dust-catching enclosures must be clamped onto the railcar doors tight enough to capture the dust. One plant uses a mechanized system in which the ends of eight loading ducts fit over the tops of the eight railcar doors and exhaust the displaced air to a scrubber. In older facilities, this may not be possible. At one location, for example, the available headroom between the bottom of the storage silo and the top of the railcars is limited, and cars are typically not of uniform height or door configuration. This situation required the design of a system to load the cars from an outside hopper adjacent to the silos, allowing for more working space. In either case, it appears that the future trend is first to contain the fugitive emission and then to treat it as a stack emission.

Potash

The most obvious form of current control technology is the use of dry cyclones, not only at drying locations, but at milling, screening, and bagging points as well. According to the New Mexico Environmental Improvement Agency, nearly all the existing potash refineries will need to control their present emissions. At this point, the agency is investigating different types of control technology and their costs (25).

STATE OF THE ART--WATER POLLUTION CONTROL TECHNOLOGY (3)

Four significant wastewater problem areas have been found in the mining and beneficiation of minerals for the chemical and fertilizer industries:

- Mine water drainage which contains acid, heavy metals, fluorides, and phosphates occurs frequently in this segment of the mineral mining industry.
- Wastewater from the fluorspar industry contains soluble fluoride in addition to suspended solids.
- Phosphate rock beneficiation produces very large quantities of slimes that have exceptionally high water retention.
- Sulfur production from onshore salt domes creates quantities of bleedwater brine containing up to 10^6 mg/m^3 of sulfides. Both the sulfides and brine cause treatment and/or disposal problems for the sulfur industry.

A detailed discussion of each problem and the control technology used is presented in Appendix D.

Control practices such as judicious selection of raw materials, good housekeeping, and minimizing leaks and spills are of limited importance in the chemical and fertilizer mineral industries. Raw materials are fixed by the composition of the ore; good housekeeping, leaks, and spills have little impact on waste loads; and noncontact water is rarely used in these processes.

The areas where control is important include:

- Wastewater containment.
- Separation and control of mine water, process water, and rain water.

Containment

Most wastewater treatment and control facilities in the chemical and fertilizer minerals industry use one or more settling ponds. Often the "pond" is actually a swamp, gully, or other low spot which will collect water. During periods of heavy rainfall, these "ponds" are often washed out, and the settled solids may be swept along as well. In many other cases, the pond may remain intact during rainfall, but its function as a settling pond is significantly impaired by the large amount of water flowing through it. In addition to problems caused by rainfall and flooding, waste containment in ponds can be troubled with ground seepage around and beneath the pond, escape through pot holes, faults and fissures below the water surface, and the physical failure of pond dams and dikes.

In most cases, satisfactory pond performance can be achieved by proper design. When this is not possible, alternative treatment methods--thickeners, clarifiers, tube and lamella separators, filters, hydrocyclones, and centrifuges--can be utilized.

Separation and Control of Wastewater

In these industries, wastewater may be separated into three categories; mine water drainage, process water, and rain water runoff.

The relative amounts and compositions and applicable control techniques of the above wastewater streams differ from one mineral category to another.

Process water and mine drainage are typically controlled and contained by pumped or gravity flow through pipes, channels, ditches and ponds. Rain water, though, is often uncontrolled; it may either contaminate process and mine drainage water, or flow off the land independently as nonpoint-source discharges. Rain water runoff increases suspended solid matter in rivers, streams, creeks or other surface water used for process water supply.

Suspended solids are the principal pollutant in the wastewater discharges of the chemical and fertilizer mineral industry. The treatment technology available for removing suspended solids from wastewater are numerous and varied, but only a relatively small number are used widely. Table 10 shows the approximate breakdown of usage for the various techniques.

TABLE 10. CONTROL TECHNOLOGY AND ITS USE FOR REMOVAL OF SUSPENDED SOLIDS (3)

Removal technique	Percent of facilities using technology
Settling ponds (unlined)	95 to 97
Settling ponds (lined)	<1
Chemical flocculation (usually with ponds)	2 to 5
Thickeners and clarifiers	2 to 5
Hydrocyclones	<1
Tube and lamella settlers	<1
Screens	<1
Filters	<1
Centrifuges	<1

Generally, the current industry experience with settling ponds shows effluents with TSS concentrations ranging from 14,000 mg/m^3 to 703,000 mg/m^3. Performance data for some treatment systems are presented in Table 11.

Chemical and fertilizer mineral operations are typically conducted in relatively isolated regions where there is no access to publicly owned wastewater treatment plants. In areas where publicly owned facilities could be used, pretreatment to reduce the load of suspended solids would be required.

TABLE 11. PERFORMANCE OF TREATMENT SYSTEMS (3)

Plant	Total suspended solids, g/m^3		Percent reduction	Treatment
	Influent	Effluent		
Sulfur:				
A	120	65	45.83	Flash strip hydrogen sulfide, oxidation with seawater.
B	-	33	-	None.
C	100	14	86.0	Spray aeration to reduce hydrogen sulfide, oxidation with seawater.
D	148	290	-	Oxidation, ponds.
E	271	50	81.55	Flue gas to strip hydrogen sulfide, ponds.
F	324	76	76.55	Oxidation, ponds.
Fluorspar:				
A	8,633	235	97.28	Pond.
B	25,356	316	98.75	Thickener, ponds.
Phosphate rock:				
A	5,620	193	96.56	Pond.
B	329	50	84.80	Ponds.
C	1,684	21	95.45	Ponds.
D	2,036	39	96.26	
E	6,500	17	99.36	Ponds.
F	2,985	645	78.39	Flocculating agent, thickener.
Lithium minerals:				
A	17,150	41	99.76	Flocculating agent, pond.
B	4,720	14	99.70	Flocculating agent, pond.
Rock salt:				
A	-	180	-	None.
B	194	216	-	None.
Salines from lake brines:				
A	1,945	703	63.86	None.

NOTE.—Dashes indicate data not available.

SECTION 6

GROWTH AND NATURE OF THE INDUSTRY

A 1975 study conducted at a number of selected mines (not limited to the chemical and fertilizer industry) showed the various mine operating expenses as a percentage of overall expenses (26). In the period 1966 to 1974, administration costs rose slightly from 16.8% to 17%. Crusher expenses dropped from 15% to 12%, while drilling and blasting costs fell from 11.2% to 10%. Loading expenses dropped from 18% to 16%, but haulage costs rose from 39% to 45%. Many mines are looking at mobile crushers and belt conveyors to reduce haulage costs.

The chemical and fertilizer mineral industry, being of a diverse nature, will be considered by mineral.

BARITE

Emerging Technology

New discoveries of barium throughout the world can be expected due to technological advances in exploration and prospecting. Improvements in mining and beneficiation will help to maintain high quality.

Demand and Production Trends

No new large-scale markets for barium are on the horizon; yet in order to assume a continuing supply, most major barite producers are conducting extensive exploration and development programs.

The U.S. oil-well-drilling industry is the major consumer of output (90%), and Nevada will continue to be the largest U.S. supplier of barite. For the next 20 yr to 25 yr, imports of barite should provide one-third of the U.S. supply. A comparison of past and present domestic barite production is presented in Figure 32.

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(26) Steidle, E. Evaluating the Role of Draglines and Shovels in Mining. Mining Congress Journal, 63(4):30-33, 1977.

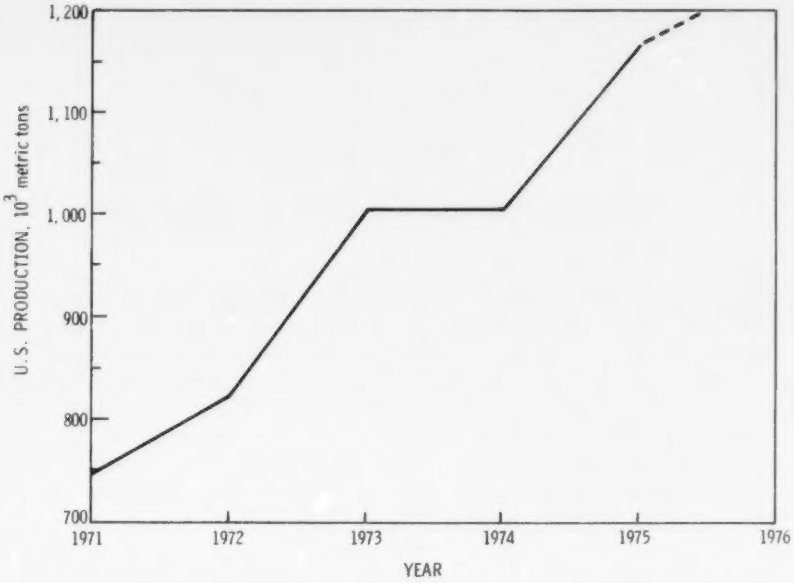

Figure 32. Production trend of barite in the United States.

BORON

Emerging Technology

The processes used to recover boron compounds from bedded deposits or from underground brines or brine lakes are not expected to change significantly by the year 2000. The solution phase is an important segment of boron recovery technique, and some improvements in evaporation of the solutions may be expected as the chemistry of various brine systems becomes better known. It would appear that additional air pollution control technology will not be needed in the U.S. Borax and Chemical Corp. plant at Boron, California. A 3-yr, $10 million program to cut dust emissions drastically was successfully concluded in 1972.

Demand and Production Trends

Present markets for boron compounds are relatively secure in terms of competition with substitutes, and the pattern may not alter radically in the future. The average annual growth rate for domestic consumption of borates is expected to be between 3.5% and 5% during the 1975 to 1980 period; this is a decrease from recent years, predicted as a consequence to the record 1973 consumption. A comparison of past and present domestic boron production is presented in Figure 33.

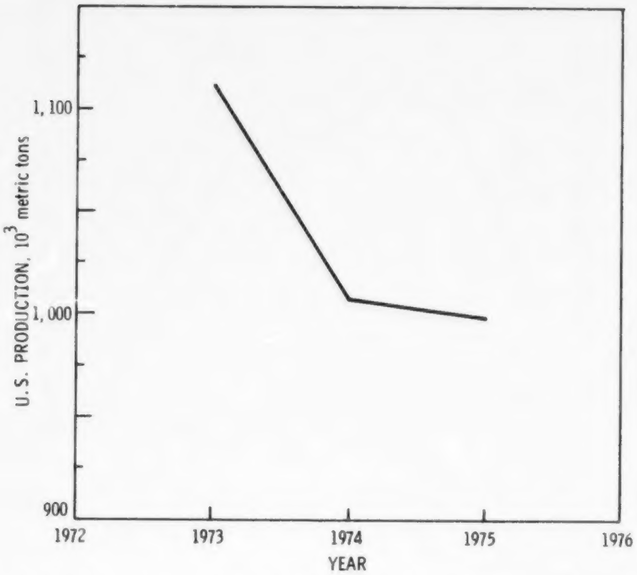

Figure 33. Production trend of boron in the United States.

FLUORSPAR

Emerging Technology

No emerging technology of significant important was found in this study.

Demand and Production Trends

The demand for fluorspar in 1976 was very sluggish. The drastic decrease in acid-grade fluorspar consumption for the past two years was at least partially caused by the plans of the U.S. Consumer Product Safety Commission and the U.S. Food and Drug Administration to ban the use of fluorocarbon propellants F-11 and F-12 in nonessential items. A further decrease in demand may occur in 1977.

In the aluminum industry, the demand for fluorspar was not as great due to pollution control measures which have made it possible to recover more of the fluorine. Byproduct fluoride recovery has become an important source. In 1976, the fluorspar equivalent recovered from phosphate rock is estimated at 72,600 metric tons, equal to 14.5% of the estimated acid-grade consumption. A comparison of past and present domestic fluorspar production is provided in Figure 34.

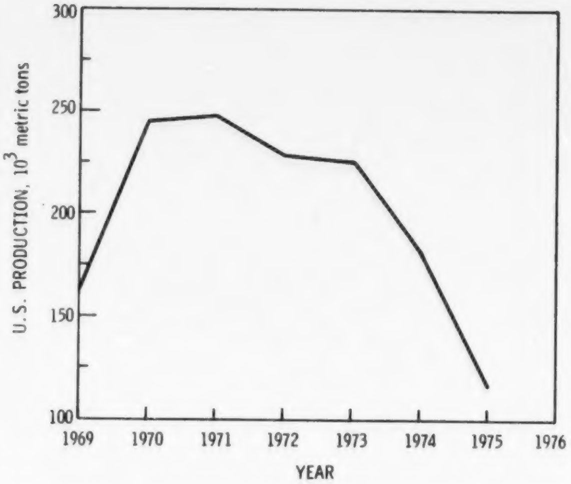

Figure 34. Production trend of fluorspar in the United States.

LITHIUM MINERALS

Emerging Technology

No emerging technology in the mining or beneficiation of these minerals was noted in this study.

Demand Trends

The aluminum industry is the largest consumer of lithium, which as lithium carborate increases production, lowers costs, and reduces fluoride emissions. Predictions are:

- The use of lithium in the aluminum industry will continue to expand.
- 1977 will show a 10% growth in demand over 1976.
- There will be little buildup of lithium inventories.

With the return of more favorable worldwide economic conditions, it may be concluded that the growth rate for lithium chemicals will increase 10% per year over the next 3-yr to 4-yr period.

PHOSPHATE ROCK

Emerging Technology

New methods to collect dust emissions from beneficiation plants, particularly in the railcar loading area, are coming into view.

The development of hydrometallurgical processes to recover phosphorus from matrix or concentrates by direct acidulation may make it possible to improve recovery rates and reduce waste disposal problems. New mining and processing techniques may be developed to utilize the potential resources of the Florida Hawthorn Formation or the Phosphoria Formation in the Western United States.

Demand and Production Trends

The past 30 yr have seen an average growth of about 6% per year in phosphate rock production. Although production will probably increase in the future, growth rates are not likely to be as consistent or as high as in the past; one authority forecasts 4.7%. Future growth will be influenced by the following emerging factors that can have serious effects:

- The current buildup of mines and fertilizer plants in countries whose objective is export.
- The increasing reliance of many western rock-producing countries on rock and fertilizer exports. Except for the United States and Australia, the plants are owned or controlled by governments and therefore are not subject to regular free business restraints.
- Most European fertilizer plants, second only to the United States in capacity, are subject to prices imposed by rock exporting countries, and these have been very high over the past 3 yr.
- Prices received by the farmer for his products may not be high enough to strengthen his continued increase in fertilizer use.

Comparisons of past and present phosphate rock demand and production are provided in Figures 35 and 36, respectively.

Florida production is expected to peak in the next 5 yr and decline thereafter. If the demand for phosphate continues to grow, then a substantial increase in production will come from the western phosphate fields. Southeastern Idaho contains about 80% of the western field reserves.

POTASH

Emerging Technology

Dust from potash plants in New Mexico may have to be controlled even more. Vegetation is sometimes affected by the emissions.

Potash mines are relatively safe and clean. Mining bedded veins is less hazardous than recovery from nonbedded deposits because of the thickness and uniformity of the potash beds.

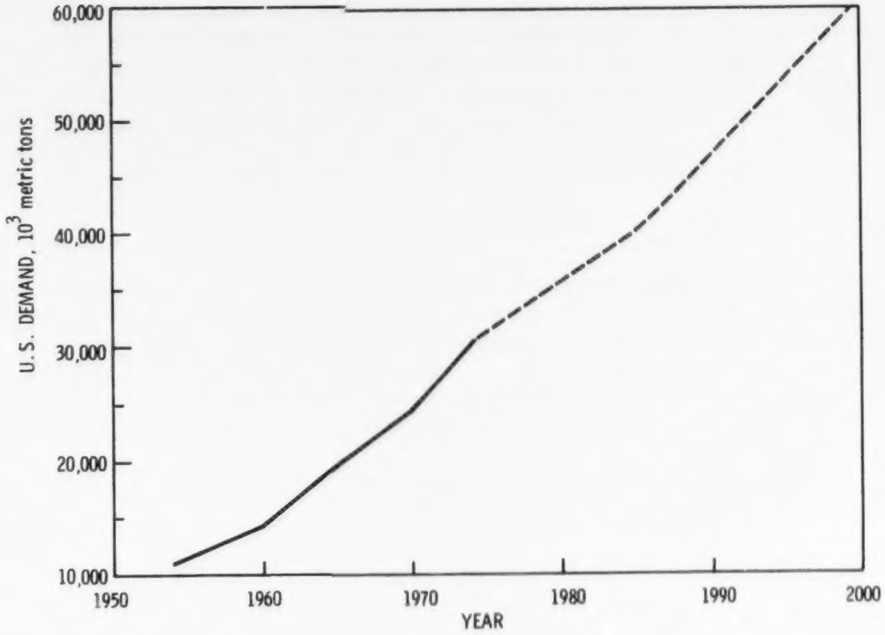

Figure 35. Demand for phosphate rock in the United States.

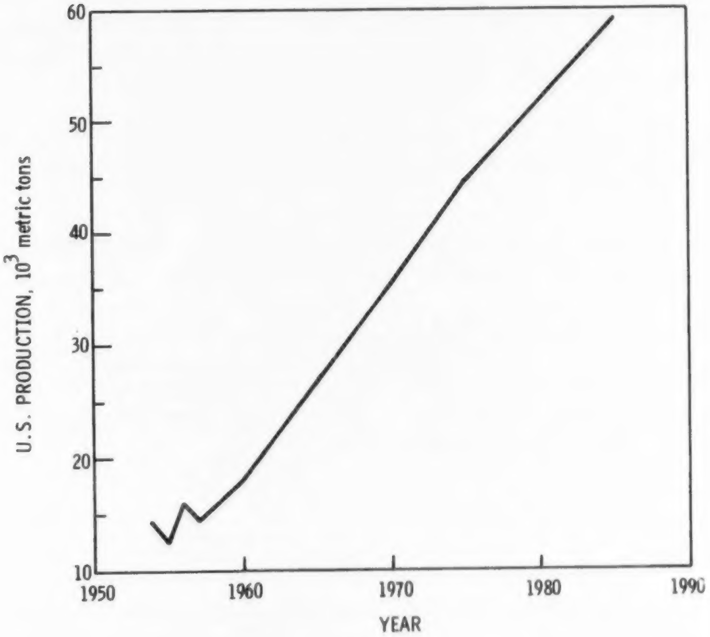

Figure 36. Production trend of phosphate rock in the United States.

Demand and Production Trends

The United States demand for potash in the year 2000 is expected to be between 9×10^6 and 14×10^6 metric tons equivalent of K_2O, representing average growth rates of 2.2% and 3.8%, respectively.

These growth rates are below those of recent past years. From 1964 to 1973, the average increase in demand was 6.3%. It is believed that this growth rate cannot be maintained because of physical limitations on consumption. Restraints on domestic fertilizer use, such as land availability, more efficient fertilizer application, new fertilizer technology, and a shift by developing nations away from importing U.S. food, should hold U.S. demand for potash to a modest growth level.

Consumption of potash by the chemical industry, which amounts to only 5% of the total, should expand at about the same rate as agricultural use.

Comparisons of past and present demand and production are provided in Figures 37 and 38, respectively.

SALT

Emerging Technology

It is likely that future improvements in salt processing will come in the form of minor changes to reduce costs or improve quality rather than as major technological breakthroughs.

Demand and Production Trends

In those countries where the industrial base is still developing, growth in demand for salt is expected to be faster than it is in the United States. Growth rates are projected to 4.0% per year for the United States and 6.3% annually for the rest of the world.

Total salt production in 1976 was up 2% over 1975, and consumption increased 5%. The principal reason for the increased consumption was greater activity in the many areas of the chemical industry which consume the bulk of the salt production. Comparisons of past and present salt demand and production are provided in Figures 39 and 40, respectively.

SODIUM SULFATE

Emerging Technology

No emerging technology of significant importance was found in this study.

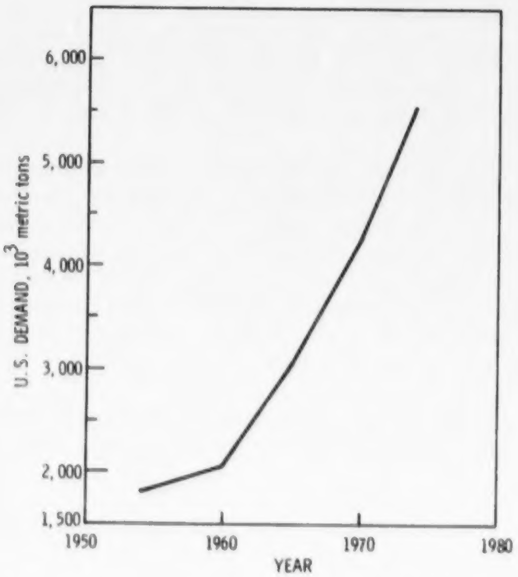

Figure 37. Demand trend for potash in the United States.

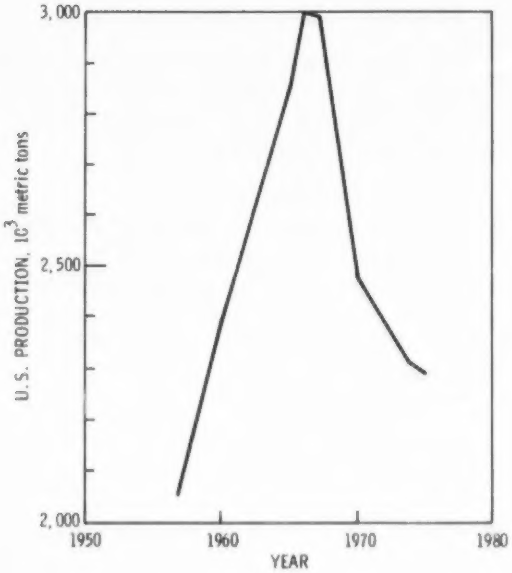

Figure 38. Production trend for potash in the United States.

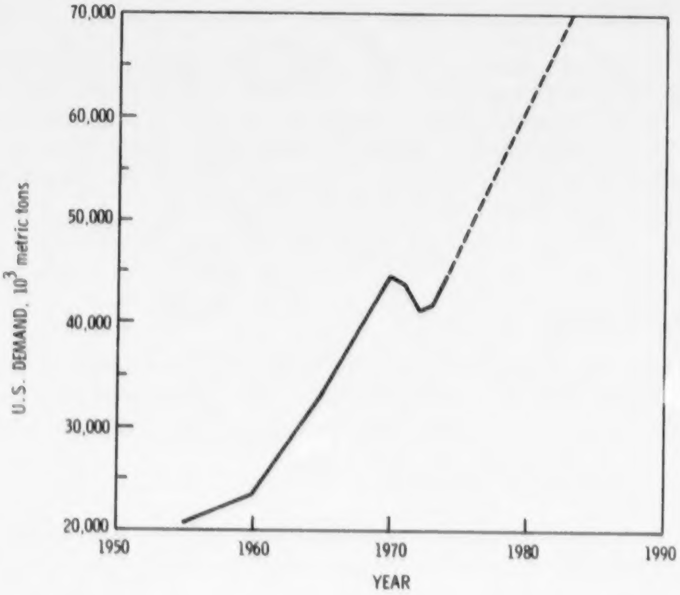

Figure 39. Demand trend for salt in the United States.

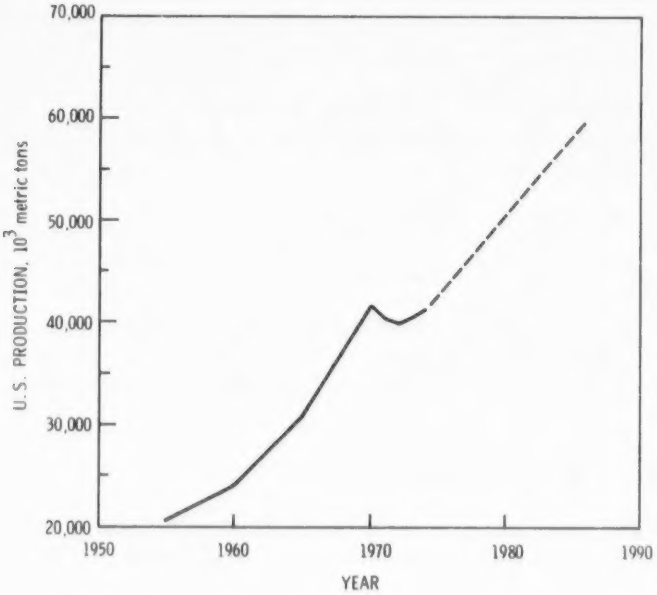

Figure 40. Production trend for salt in the United States.

Demand and Production Trends

Consumption figures for sodium sulfate are not easily obtained, and those appearing in the literature are often unreliable. No attempt is usually made to forecast cumulative demand or growth rate for this commodity. Comparisons of past and present sodium sulfate demand and production are provided in Figures 41 and 42, respectively.

SULFUR

Emerging Technology

If the results of preliminary testing are favorable, the use of sulfur as a substitute for asphalt in road paving could open a major new volume sulfur market before the end of the decade.

Demand and Production Trends

At the end of 1976, demand for sulfur began to strengthen. These improved levels of demand should carry into the year 1977.

Voluntary sulfur production (particularly Frasch process production in the United States) has been faced with rapidly rising production costs and prices which are not high enough to attract the capital necessary for exploration and development of new sulfur sources.

In the longer term, demand for sulfur from the rapidly growing world fertilizer market will continue to increase while the outlook for additional supplies of sulfur remains uncertain.

Comparisons of past and present consumption and production of Frasch sulfur in the United States are presented in Figures 43 and 44, respectively.

TRONA ORE (SODA ASH)

Emerging Technology

Solution mining of trona is technically possible, but no successful attempts have been made. A new process or innovation in the direction of solution mining might reduce the cost of mining considerably.

Demand and Production Trends

U.S. demand for soda ash is predicted to reach 14.2 million metric tons/yr by 2000, indicating a growth rate of 3.0% per year.

U.S. production of natural soda ash from trona or alkaline brines is increasing rapidly. Between 1961 and 1974, average annual natural soda ash output increased more than 13% per year.

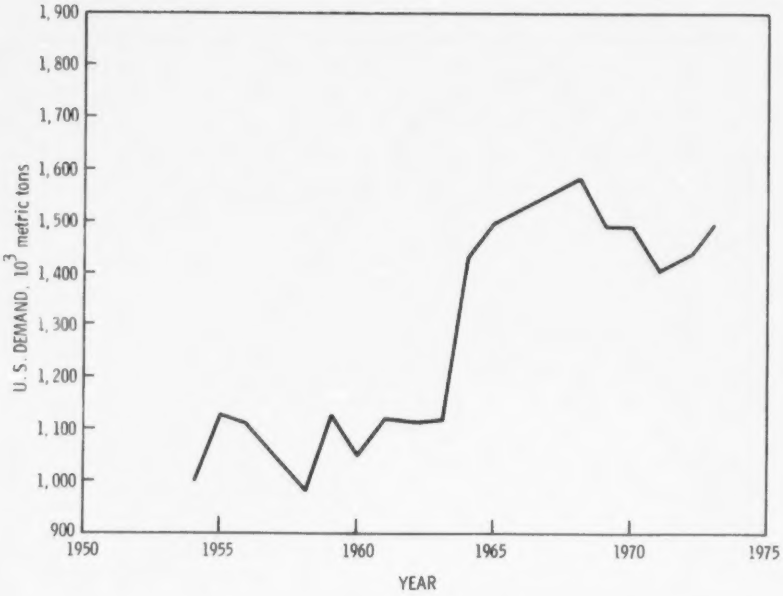

Figure 41. Demand trend for sodium sulfate in the United States.

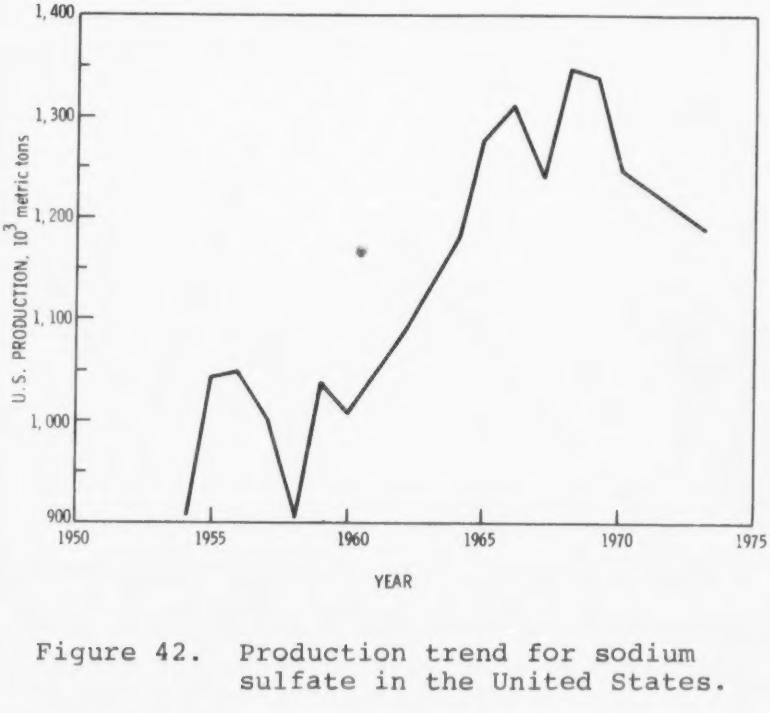

Figure 42. Production trend for sodium sulfate in the United States.

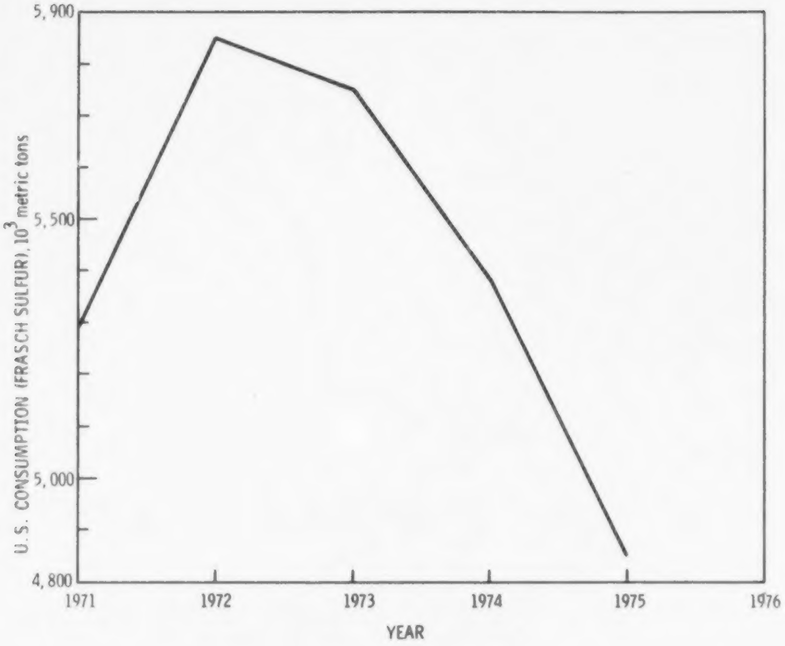

Figure 43. Consumption trend of Frasch sulfur in the United States.

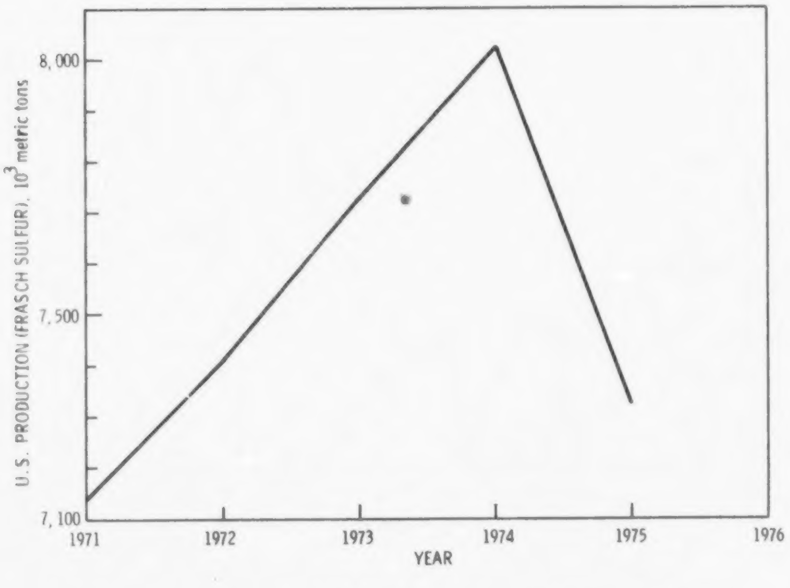

Figure 44. Production trend for Frasch sulfur in the United States.

Capacity is expected to reach 7.85 million metric tons/yr by 1978. Comparisons of past and present U.S. demand and production of soda ash (natural and synthetic) are provided in Figures 45 and 46, respectively.

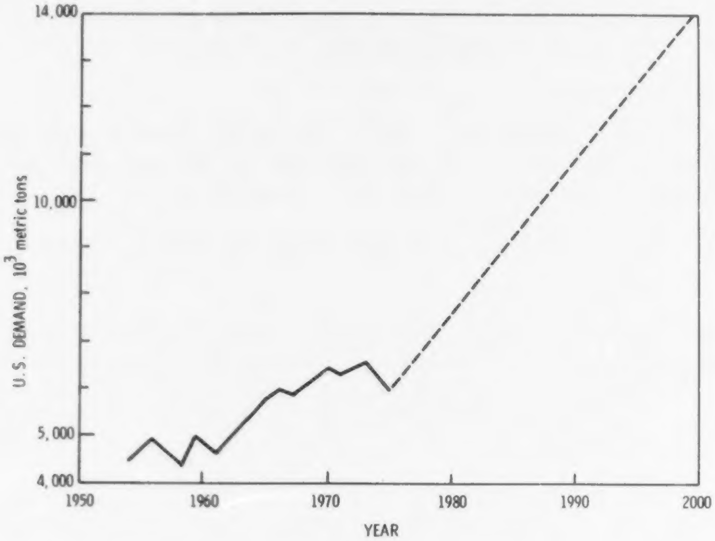

Figure 45. Demand for soda ash in the United States.[a]

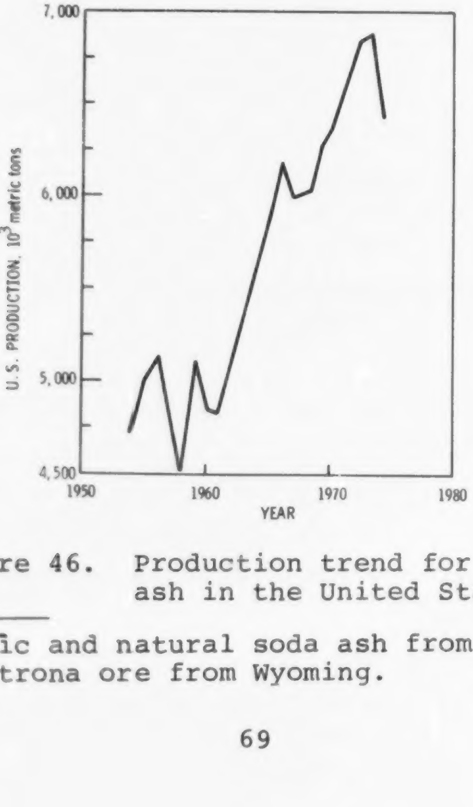

Figure 46. Production trend for soda ash in the United States.[a]

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[a] Includes synthetic and natural soda ash from Searles Lake, California, and trona ore from Wyoming.

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APPENDIX A

PRINCIPAL PRODUCERS AND THEIR GEOGRAPHICAL DISTRIBUTION (27, 28)

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TABLE A-1. PRINCIPAL PRODUCERS OF BARITE

Company	Type of activity	County	State
Alaska Barite Co.	Open pit	Southeastern Alaska	Alaska
Dresser Minerals	Mine and plant	Hot Spring	Arkansas
NL Industries, Inc.	Mine and plant	Hot Spring	Arkansas
Industrial Minerals Co.	Mine and plant	Shasta	California
New Riverside Ochre Co.	Open pit mine	Bartow	Georgia
Paga Mining Co., Div. Thompson-Weinman & Co.	Open pit mine and grinding mill	Bartow	Georgia
Pfizer, Inc., Minerals, Pigments & Metals Div.	Grinding plant	St. Clair	Illinois
Dresser Minerals Division, Dresser Industries, Inc.	Grinding plant	Orleans and Calcasieu	Louisiana[a]
Milchem, Inc.	Grinding plant	Orleans	Louisiana[a]
NL Industries Inc., Baroid Div.	Grinding plant	Orleans	Louisiana[a]
Dresser Minerals Div.	Mine	Washington	Missouri
Milchem, Inc.	Mine and mill	Washington	Missouri
NL Industries, Inc., Baroid Div.	Mine and mill	Washington	Missouri
NL Industries, Inc., Delore Div.	Mill	St. Louis	Missouri
Pfizer & Co.	Mine and mill	Washington	Missouri
NL Industries, Inc., Baroid Div.	Open pit mine	Elko	Nevada
Dresser Minerals Division, Dresser Industries, Inc.	Open pit mine	Lander	Nevada
FMC Corp.	Open pit mine	Lander	Nevada
Milchem, Inc., Mineral Div.	Open pit mine	Lander	Nevada
NL Industries, Inc., Baroid Div.	Two open pit mines and plant	Monroe	Tennessee
B. C. Wood	Open pit mine and plant	Loudon	Tennessee
Dresser Industries, Inc.	Grinding plant	Cameron	Texas[a]
The Milwhite Co., Inc.	Grinding plant	Harris	Texas[a]
National Lead Co.	Grinding plant	Nueces	Texas[a]

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[a] Grinds imported ore.

TABLE A-2. PRINCIPAL PRODUCERS OF BORON

Company	Type of activity	County	State
Kerr-McGee Chemical Corp.[a]	Dry lake brines	San Bernadino	California
Tenneco, Inc.	Open pit mine	Inyo	California
United States Borax & Chemical Corp.	Open pit mine	Inyo and Kern	California

[a] Boron minerals and compounds produced.

TABLE A-3. PRINCIPAL PRODUCERS OF FLUORSPAR

Company	Type of activity	County	State
Ozark-Mahoning Co.	Underground mine and plant	Jackson	Colorado
Minerva Company, mining division of Minerva Oil Co.			
Crystal Group	Underground mines and mill	Hardin	Illinois
Minerva No. 1	Underground mines and mill	Hardin	Illinois
Ozark-Mahoning Co.	Underground mines and mill	Hardin	Illinois
Calvert City Chemical Co.	Underground mine and mill	Crittenden and Livingston	Kentucky
Roberts Mining Co.	Mine and plant	Ravalli	Montana
J. Irving Crowell, Jr.	Underground mine	Nye	Nevada
D & F Minerals Co.	Mine	Brewster	Texas
Spor Bros.	Open pit and underground mines	Juab	Utah
U.S. Energy Corp.	Open pit mine	Juab	Utah
Willden Fluorspar Co.	Underground mine	Juab	Utah

TABLE A-4. PRINCIPAL PRODUCERS OF LITHIUM MINERALS

Company	Type of activity	County	State
Kerr-McGee Chemical Corp.	Dry lake brines	San Bernardino	California
Foote Mineral Co.	Dry lake brines	Esmeralda	Nevada
Foote Mineral Co.	Open pit mine and plant	Cleveland	N. Carolina
Lithium Corp. of America, Inc.	Open pit mine and plant	Gaston	N. Carolina

TABLE A-5. PRINCIPAL PRODUCERS OF MINERAL PIGMENTS (IRON OXIDE PIGMENTS)

Company	Type of activity	County	State
Leber Mining Co.[a]	Mine	Nevada	Arkansas
New Riverside Ochre Co.[b]	Mine and plant	Bartow	Georgia
Pfizer, Inc., Minerals, Pigments and Metals Div.[a]	Plant	St. Clair	Illinois
Prince Manufacturing Co.[c]	Plant	Adams	Illinois
George B. Smith Chemical Works[c]	Plant	Kane	Illinois
Cleveland-Cliffs Iron Co.[d]	Mine	Marquette	Michigan
Cities Service Co.[d]	Plant	Mercer and Middlesex	New Jersey
E. I. du Pont de Nemours & Co., Inc.[d]	Plant	Essex	New Jersey
Allegheny Ludlum Steel Corp.[a]	Plant	Allegheny	Pennsylvania
Lanzendorfer Minerals Co.[a]	Pit	Cambria	Pennsylvania
Minerals, Pigments & Metals Div., Chas. Pfizer & Co., Inc.[c]	Plant	Northampton	Pennsylvania
The Prince Manufacturing Co.[c]	Plant	Carbon	Pennsylvania
Reichard-Coulston, Inc.[c]	Plant	Northampton	Pennsylvania
Hoover Color Corp.[a]	Strip mine	Pulaski	Virginia
Delta Oil Co.[c]	Plant	Milwaukee	Wisconsin

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[a] Iron oxide pigments (crude) produced. [b] Iron oxide pigment materials produced.

[c] Iron oxide pigments (finished) produced. [d] Iron oxide pigments (manufactured) produced.

TABLE A-6. PRINCIPAL PRODUCERS OF PHOSPHATE ROCK

Company	Type of activity	County	State
Agrico Chemical Co.	Three open pit mines	Polk	Florida
Borden, Inc.	Open pit mine	Polk	Florida
Brewster Phosphates	Open pit mine	Polk	Florida
Gardinier, Inc.	Open pit mine	Polk	Florida
W. R. Grace & Co.	Open pit mine	Polk	Florida
International Minerals & Chemical Corp.	Three open pit mines	Polk	Florida
Mobil Oil Corp., Chemical Div.	Two open pit mines	Polk	Florida
Occidental Petroleum Corp., Suwannee River Phosphate Div.	Open pit mine	Hamilton	Florida
Swift Chemical Co.	Two open pit mines	Polk	Florida
U.S.S. Agri-Chemicals, Inc.	Open pit mine	Polk	Florida
Beker Industries	Mine and plant	Caribou	Idaho
Monsanto Co.	Mine and plant	Caribou	Idaho
J. R. Simplot Co.	Mine	Bingham	Idaho
Stauffer Chemical Co.	Mine and plant	Caribou	Idaho
Stauffer Chemical Co.	Mine	Caribou	Idaho
Cominco American, Inc.	Mine and plant	Powell	Montana
Stauffer Chemical Co.	Plant	Silver Bow	Montana
Texasgulf, Inc.	Open pit mine and plant	Beaufort	North Carolina
Hooker Chemical Corp.	Open pit mines and plant	Hickman and Maury	Tennessee
Monsanto Co.	Open pit mines and plant	Giles, Maury, Williamson	Tennessee
Stauffer Chemical Co.	Open pit mines and plant	Giles and Maury	Tennessee
Tennessee Valley Authority	Open pit mines and plant	Maury and Williamson	Tennessee
Stauffer Chemical Co.	Open pit-underground mine	Rich	Utah
Stauffer Chemical Co.	Open pit mine and beneficiation plant	Unitah	Utah
Stauffer Chemical Co. of Wyoming	Open pit mine and beneficiation plant	Lincoln	Wyoming

TABLE A-7. PRINCIPAL POTASH PRODUCERS

Company	Type of activity	County	State
Kerr-McGee Chemical Corp.[a]	Dry lake brines	San Bernardino	California
AMAX Chemical Corp.	Underground mine and refinery	Eddy	New Mexico
Duval Corp., Potash Division	Two underground mines and refinery	Eddy	New Mexico
International Minerals & Chemical Corp.	Underground mine	Eddy	New Mexico
Kerr-McGee Corp.	Underground mine	Lea	New Mexico
National Potash Co.	Underground mine	Eddy	New Mexico
Potash Co. of America, a division of Ideal Basic Industries, Inc.	Underground mine	Eddy	New Mexico
Mississippi Co.	Underground mine	Eddy	New Mexico
Kaiser Aluminum and Chemical Corp.[a]	Brine treatment	Tooele	Utah
Texas Gulf Sulfur Co.[a]	Brine treatment	Grand	Utah

[a] Potassium salts produced.

TABLE A-8. PRINCIPAL PRODUCERS OF ROCK SALT, SALT FROM BRINE, AND EVAPORATED SALT

Company	Type of activity	County	State
Olin Corp.	Brine wells	Washington	Alabama
Leslie Salt Co.	Solar evaporation and open pit mine	Alameda, Napa, San Bernardino, San Mateo	California
Metropolitan Water Dist. of Southern California	Solar evaporation	San Bernardino	California
Pacific Salt & Chemical Co.	Solar evaporation	San Bernardino	California
Southwest Salt Co.	Solar evaporation	San Bernardino	California
Western Salt Co.	Solar evaporation	Kern and San Diego	California
Tanaka Hawaiian Salt	Solar evaporation	Oahu	Hawaii
American Salt Corp.	Wells and underground	Rice	Kansas
Carey Salt Co.	Wells and underground	Reno	Kansas
Independent Salt Co.	Underground	Ellsworth	Kansas
Morton Salt Co.	Wells	Reno	Kansas
Vulcan Materials Co., Chemicals Div.	Brine wells	Sedgwick	Kansas
Allied Chemical Corp., Industrial Chemicals Div.	Brine wells	Iberville	Louisiana
Cargill, Inc.	Underground mine	St. Mary	Louisiana
Diamond Crystal Salt Co., Jefferson Island Div.	Underground mine	Iberia	Louisiana
The Dow Chemical Co.	Brine wells	Iberville	Louisiana
International Salt Co. Avery Mine & Refinery	Underground mine	Iberia	Louisiana
Morton Salt Co.	Underground mine	Iberia	Louisiana
PPG Industries, Inc., Industrial Chemical Division	Underground mine	Calcasieu	Louisiana
Diamond Crystal Salt Co.	Brine wells and processing plant: salt	St. Clair	Michigan

(continued)

TABLE A-8 (continued)

Company	Type of activity	County	State
The Dow Chemical Co.:			
Ludington plant	Brine wells and processing plant: bromine, calcium-magnesium compounds, magnesium compounds	Mason	Michigan
Midland plant	Brine wells and processing plant: bromine, calcium-magnesium compounds, iodine, magnesium compounds, salt	Midland	Michigan
Hooker Chemical Corp.	Brine wells and processing plant: salt	Muskegon	Michigan
International Salt Co., Inc.	Underground salt mine	Wayne	Michigan
Martin Marietta Chemicals, Refractories Div.	Brine wells and processing plant: magnesium compounds	Manistee	Michigan
Michigan Chemical Corp. St. Louis Plant	Brine wells and processing plant: bromine, calcium magnesium compounds, magnesium compounds, salt	Gratiot	Michigan
Morton Chemical Co., div. Morton-Norwich Products, Inc.	Brine wells and processing plant: bromine, magnesium compounds	Manistee	Michigan
Morton Salt Co., div. of Morton-Norwich Products, Inc.:			
Manistee plant	Brine wells and processing plant: salt	Manistee	Michigan
Port Hurton plant	Brine wells and processing plant: salt	St. Clair	Michigan
Pennwalt Corp.	Brine wells and processing plant: salt	Wayne	Michigan
Wilkinson Chemical Corp.	Brine wells and processing plant: calcium-magnesium compounds	Lapeer	Michigan
BASF Wyandotte Corp.	Brine wells and processing plant: salt	Wayne	Michigan

(continued)

TABLE A-8 (continued)

Company	Type of activity	County	State
Huck Salt Co.	Solar evaporation	Churchill	Nevada
Teledyne Potash Co.	Solar evaporation and rock salt	Eddy	New Mexico
Morton Salt Co.	Well	Wyoming	New York
Watkins Salt Co., Inc.	Well	Schuyler	New York
Cargill, Inc.	Underground	Tompkins	New York
International Salt Co.	Underground	Livingston	New York
Industrial Chemicals Div., Allied Chemical Corp.	Well	Onondaga	New York
Hardy Salt Co.	Well and plant	Williams	North Dakota
Diamond Shamrock Chemical Co., unit of Diamond Shamrock Corp.	Well	Lake	Ohio
PPG Industries, Inc.	Well	Summit	Ohio
Diamond Crystal Salt Co.	Well	Summit	Ohio
Excelsior Salt Works, Inc.	Well	Meigs	Ohio
Morton Salt Co., a division of Morton International, Inc.	Well	Wayne	Ohio
International Salt Co.	Underground	Cuyahoga	Ohio
Morton Salt Co., a division of Morton International, Inc.	Underground	Lake	Ohio
Blackmon Salt Co.	Solar evaporation	Woods	Oklahoma
Western Salt Co.	Solar evaporation	Harman	Oklahoma
Diamond Shamrock Corp.	Brine wells	Chambers	Texas
The Dow Chemical Co.	Brine wells	Brazoria	Texas
Montex Chemical Co.	Brine wells	Ward	Texas
Morton Salt Co.	Underground mine and brine wells	Van Zandt	Texas
PPG Industries	Brine wells	Duval	Texas
Phillips Petroleum Co.	Brine wells	Hutchinson	Texas
Texas Brine Corp.	Brine wells	Harris, Jefferson, Matagorda	Texas
United Salt Corp.	Underground mine and brine wells	Fort Bend and Harris	Texas
Vulcan Materials Co.	Brine wells	Yoakum	Texas

(continued)

TABLE A-8 (continued)

Company	Type of activity	County	State
American Salt Co.	Lake brine processing plant	Tooele	Utah
Great Salt Lake Minerals & Chemicals Corp.	Solar evaporation	Weber	Utah
Morton Salt Co., a division of Morton International, Inc.	Lake brine processing plant	Salt Lake	Utah
Industrial Chemicals Div. Allied Chemical Corp.	Plant	Marshall	West Virginia
Inorganic Chemical Div. FMC Corp.	Mine	Tyler	West Virginia
PPG Industries, Inc., Chemical Div.	Plant	Marshall	West Virginia

TABLE A-9. PRINCIPAL PRODUCERS OF SODIUM SULFATE

Company	Type of activity	County	State
Kerr-McGee Chemical Corp.	Dry lake brines	San Bernardino	California
Stauffer Chemical Co.	Dry lake brines	San Bernardino	California
United States Borax & Chemical Corp.	Open pit mine	Kern	California
Ozark-Mahoning Co.	Open pit mine	Gaines and Terry	Texas
Great Salt Lake Minerals & Chemicals Corp.	Salt lake brine	Weber	Utah

TABLE A-10. PRINCIPAL PRODUCERS OF SULFUR

Company	Type of activity	County	State
Freeport Minerals Co.	Frasch process	Jefferson, Plaquemines, Terrebonne	Louisiana
Texas Gulf, Inc.	Frasch process	Lafourche	Louisiana
Atlantic Richfield Co.	Frasch process	Pecos	Texas
Duval Corp.	Frasch process	Culberson	Texas
Texasgulf, Inc.	Frasch process	Jefferson, Liberty Wharton	Texas

TABLE A-11. PRINCIPAL PRODUCERS OF TRONA ORE

Company	Type of activity	County	State
Allied Chemical Corp., Industrial Chemicals Division	Underground mine and refinery	Sweetwater	Wyoming
FMC Corp., Inorganic Chemicals Division	Underground mine and refinery	Sweetwater	Wyoming
Stauffer Chemical Co. of Wyoming	Underground mine and refinery	Sweetwater	Wyoming

APPENDIX B

EMISSION FACTOR ESTIMATES FOR MINING AND BENEFICIATING OPERATION

An emission factor estimate for the mineral of interest is obtained by coupling the process information presented in the source description section with actual emission factors for related industries.

A list of typical mining and beneficiation operations and their corresponding emission factors is presented in Table B-1 (24, 25, 29). Following the table, specific emission factors for each mineral have been totaled; the results are shown in Tables B-2 through B-12.

The method helps to relate emission potentials for the minerals; it does not give the definitive answers which can be obtained only by actual sampling.

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(29) Blackwood, T. R., P. K. Chalekode, and R. A. Wachter. Source Assessment: Crushed Stone. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio, July 1977. 91 pp.

TABLE B-1. LIST OF UNIT OPERATIONS AND CORRESPONDING EMISSION FACTORS

Unit operation	Respirable particulates, g/kg	Total particulates, g/kg	Type of industry	Reference
Blasting	0.0000088	0.000052	Crushed stone	29
Drilling (wet)	0.000016	0.00016	Crushed stone	29
Quarrying	0.0011	0.011	Crushed stone	29
Primary crushing and unloading	0.0013	0.013	Crushed stone	29
Secondary crushing and screening	0.00034	0.00062	Crushed stone	29
Tertiary crushing and screening	0.000067	0.00036	Crushed stone	29
Fines crushing and screening	0.000015	0.000092	Crushed stone	29
Conveying	0.000011	0.0017	Crushed stone	29
Loading trucks	0.000045	0.00017	Crushed stone	29
Unloading trucks	0.000054	0.00013	Crushed stone	29
Transport (wet)	0.00020	0.0012	Crushed stone	29
Dragline (overburden removal)	0.0085[a]	0.085	Coal	29
Dragline (ore removal)	0.00004[a]	0.0004	Coal	24
Bagging	0.0002[a]	0.002	Potash	25
Drying	0.0071[a]	0.071	Phosphate rock	-[b]
Silo storage	0.011[a]	0.105	Phosphate rock	-[b]
Railcar loading	0.016[a]	0.161	Phosphate rock	-[b]

[a] Assuming respirable particulates = total particulates x 0.1.

[b] Values as reported in Section 4, Table 7.

TABLE B-2. BARITE

Unit operation typical to the industry	Respirable particulates, g/kg	Total particulates, g/kg
Quarrying	0.0011	0.011
Loading trucks	0.000045	0.00017
Unloading trucks	0.000054	0.00013
Conveying	0.00011	0.0017
Primary crushing and unloading	0.0013	0.013
Fines crushing and screening	0.000015	0.000092
Drying	0.014[a]	0.140
Bagging	0.0002[a]	0.002
Total:		
g/kg	0.017	0.17
g/metric ton	17	170

[a] Assuming respirable particulates = total particulates x 0.1.

TABLE B-3. BORATES

Unit operation typical to the industry	Respirable particulates, g/kg	Total particulates, g/kg
Quarrying	0.0011	0.011
Conveying	0.000011	0.0017
Primary crushing and unloading	0.0013	0.013
Secondary crushing and screening	0.00034	0.00062
Drying	0.0071[a]	0.071
Storage silo	0.011[a]	0.105
Drilling (wet)	0.000016	0.00016
Blasting	0.0000088	0.000052
Total:		
g/kg	0.021	0.203
g/metric ton	21	203

[a] Assuming respirable particulates = total particulates x 0.1.

TABLE B-4. FLUORSPAR

Unit operation typical to the industry	Respirable particulates, g/kg	Total particulates, g/kg
Primary crushing and unloading	0.0013	0.013
Secondary crushing and screening	0.00034	0.00062
Tertiary crushing and screening	0.000067	0.00036
Fines crushing and screening	0.000015	0.000092
Conveying	0.000011	0.0017
Drying	0.0071[a]	0.071
Silo storage	0.011[a]	0.105
Railcar loading	0.016[a]	0.161
Total:		
g/kg	0.036	0.35
g/metric ton	36	350

[a] Assuming respirable particulates = total particulates x 0.1.

TABLE B-5. LITHIUM MINERALS

Unit operation typical to the industry	Respirable particulates, g/kg	Total particulates, g/kg
Quarrying	0.0011	0.011
Loading trucks	0.000045	0.00017
Unloading trucks	0.000054	0.00013
Primary crushing and unloading	0.0013	0.013
Conveying	0.000011	0.0017
Drying	0.0071[a]	0.071
Bagging	0.0002[a]	0.002
Total:		
g/kg	0.010	0.10
g/metric ton	10	100

[a] Assuming respirable particulates = total particulates x 0.1.

TABLE B-6. MINERAL PIGMENTS

Unit operation typical to the industry	Respirable particulates, g/kg	Total particulates, g/kg
Loading trucks	0.000045	0.00017
Unloading trucks	0.000054	0.00013
Primary crushing and unloading	0.0013	0.013
Conveying	0.000011	0.0017
Drying	0.0071[a]	0.071
Silo storage	0.011	0.105
Bagging	0.0002	0.002
Total:		
g/kg	0.020	0.19
g/metric ton	20	190

[a] Assuming respirable particulates = total particulates x 0.1.

TABLE B-7. BRINE SALT

Unit operation typical to the industry	Respirable particulates, g/kg	Total particulates, g/kg
Drilling (wet)	0.000016	0.00016
Drying	0.0071[a]	0.071
Primary crushing and unloading	0.0013	0.013
Bagging	0.0002[a]	0.002
Total:		
g/kg	0.009	0.086
g/metric ton	9	86

[a] Assuming respirable particulates = total particulates x 0.1.

TABLE B-8. ROCK SALT

Unit operation typical to the industry	Respirable particulates, g/kg	Total particulates, g/kg
Underground drilling (wet)	0.000016	0.00016
Underground blasting	0.0000088	0.000052
Underground conveying	0.000011	0.0017
Underground primary crushing and unloading	0.0013	0.013
Total (underground)	0.00134	0.0149
0.5 x Total (underground)	0.00067	0.0075
Surface secondary crushing and screening	0.00034	0.00062
Surface bagging	0.0002[a]	0.002
Total:		
g/kg	0.0012	0.010
g/metric ton	1.2	10

[a] Assuming respirable particulates = total particulates x 0.1.

TABLE B-9. SOLAR EVAPORATED SALT

Unit operation typical to the industry	Respirable particulates, g/kg	Total particulates, g/kg
Drying	0.0071[a]	0.071
Primary crushing and unloading	0.0013	0.013
Bagging	0.0002[a]	0.002
Total:		
g/kg	0.009	0.086
g/metric ton	9	86

[a] Assuming respirable particulates = total particulates x 0.1.

TABLE B-10. SODIUM SULFATE

Unit operation typical to the industry	Respirable particulates, g/kg	Total particulates, g/kg
Drying	0.0071[a]	0.071
Bagging	0.0002[a]	0.002
Total:		
g/kg	0.0073	0.073
g/metric ton	7.3	73

[a] Assuming respirable particulates = total particulates x 0.1.

TABLE B-11. SULFUR

Unit operation typical to the industry	Respirable particulates, g/kg	Total particulates, g/kg
Drilling (wet)	0.000016	0.00016
Total:		
g/kg	0.000016	0.00016
g/metric ton	0.016	0.16

TABLE B-12. TRONA ORE

Unit operation typical to the industry	Respirable particulates, g/kg	Total particulates, g/kg
Drilling (wet)	0.000016	0.00016
Blasting	0.0000088	0.000052
Primary crushing and unloading	0.0013	0.013
Conveying	0.000011	0.0017
Total (underground)	0.0013	0.015
0.5 x Total underground)	0.0007	0.008
Secondary crushing and screening	0.00034	0.00062
Drying	0.0071[a]	0.071
Total:		
g/kg	0.011	0.110
g/metric ton	11	110

[a] Assuming respirable particulates = total particulates x 0.1.

APPENDIX C

STATE PARTICULATE EMISSION BURDENS FROM THE PRODUCTION OF SPECIFIC MATERIALS

TABLE C-1. STATE PARTICULATE EMISSION BURDENS FROM THE PRODUCTION OF SPECIFIC MATERIALS

Material produced	State	Overall particulate emissions,[a] 10^3 metric tons/yr	Particulate emissions due to production, metric tons/yr	Contribution from production to overall state emission, %
Barite[b]	Alaska	13.9	20.7	0.15
	Arkansas	138	25.8	0.02
	California	1,010	1.7	-[c]
	Missouri	1,150	30.3	-
	Nevada	305	84.6	0.03
	Tennessee	410	3.2	-
Borates	California	1,010	203	0.02
Fluorspar[b]	Utah	71.7	1.5	-
Phosphate rock	Florida	226.5	16,030	7.1
	Idaho	55.5	480	0.87
	Montana	872	480	0.06
	North Carolina	481	801	0.17
	Tennessee	410	801	0.20
	Utah	71.7	480	0.67
	Wyoming	75.4	480	0.64
Potash[b]	New Mexico	103	16,783	16
Brine salt[b]	Kansas	348	54	0.02
	Louisiana	380380	293	0.08
	Michigan	706	347	0.05
	New York	160	243	1.15
	Ohio	1,770	259	0.01
	Texas	549	808	0.15
	Utah	71.7	37	0.05
Rock salt	Kansas	348	12.7	-
	Louisiana	380	79.5	0.02
	Michigan	706	3.4	-
	New York	160	18.9	0.01
	Ohio	1,770	121	-
Solar evaporated salt[b]	California	1,010	118	0.01
	New Mexico	103	6	-
	Oklahoma	93.6	0.4	-
	Utah	71.7	19	0.03
Sodium sulfate	California	1,010	81	-
	Texas	549	27	-
	Utah	71.7	27	-
Sulfur	Louisiana	380	0.48	-
	Texas	549	0.60	-
Trona ore	Wyoming	75.4	405	0.54

[a] Total particulate emissions = (total metric tons of emission/metric tons of production)[metric tons of production (per state)/year].

[b] Production data for all producing states are not available.

[c] Dashes indicate negligible emission, <0.01%.

APPENDIX D

MAJOR WASTEWATER PROBLEM AREAS

MINE WATER DRAINAGE (3)

Most chemical and fertilizer mineral mining operations have small amounts of drainage which need little or no treatment. The exceptions are described below:

- When the ore in phosphate rock mines lies below the water table, the water table may be lowered by massive pumping to drain the mine and surrounding area. An alternate method is to mine below the water level.
- Salt mines frequently have seepage and drainage problems which may be handled by pumping the water to the surface for subsequent treatment and disposal, or pumping the drainage directly to a nearby aquifer.
- Fluorspar mine drainage varies to a great extent. The quality of the water in terms of suspended solids and dissolved fluoride is better than the quality of wastewater from associated processing plants.
- Barite mines normally have small amounts of mine drainage, but at least one plant has a large drainage flow of acidic water which contains dissolved heavy metal salts.

FLUORSPAR WASTEWATER (3)

Process wastewater from fluorspar operations has a high content of suspended solids and fluoride. Fluorides are currently being discharged without treatment.

PHOSPHATE ROCK SLIMES

Disposal problems associated with the slime from Florida land-pebble water plants are by far the most serious environmental problems facing the Florida phosphate rock industry. The slimes problem, in fact, may well be the most significant of all fertilizer production problems.

Phosphate slime, which constitutes about one-third of the total matrix mined, has been a disposal problem to the phosphate industry ever since mining began in Polk County, Florida, about 1890. The disposal problem increased significantly in the late 1920's with the introduction of the flotation process. This is because the matrix mined for flotation has a higher clay content than ore mined before the use of flotation.

The treatment of slimes consists of gravity settling through an extensive use of ponds. At 3% to 5% solids, the slimes either flow by gravity through open ditches with necessary lift stations or are pumped directly to the settling ponds.

After an initial settling and clarification period, some of the water containing the slimes is reclaimed and can be recycled to the plant. However, subsequent settling of the slimes to release more water is very slow. The slow settling characteristic, or inability to dewater, is a common property of Florida phosphate slimes. At present, over 202.5×10^6 m^2 of active and inactive settling areas exist, surrounded by more than 480 km of earth dams. About 16.2×10^6 m^2 of new settling areas are being constructed each year. The magnitude of the disposal problem is readily appreciated when it is realized that the industry produces some 36 million metric tons of these waste clays (dry basis) annually. A chemical analysis of slimes solids is presented in Table D-1 (30).

Current dewatering concepts are briefly presented in Figure D-1. Other processes which have been proposed include freeze-thawing, electro-osmosis, chemical coagulation, spherical agglomeration, and drainage systems.

These potential solutions to the problem are being evaluated, and the likelihood of finding feasible alternatives to above-ground impoundments appears very good.

SULFUR PRODUCTION (3)

Salt dome sulfur producers have to treat and dispose of large amounts of bleedwater. Two problems are presented; the removal of sulfides and the disposal of the remaining brine. Currently, there is no economical way to desalt brine. Waste brine must be disposed of immediately in brackish or salt water, or held to be discharged intermittently at specified times.

The industry has two types of bleedwater treatment plants for the removal of sulfides prior to discharge. Examples of each are presented in Figures D-2 and D-3.

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(30) Lamont, W. E., J. T. McLendon, L. W. Clements, Jr., and I. L. Feld. Characterization Studies of Florida Phosphate Slimes. ROI 8089, U.S. Department of the Interior, Washington, D.C., 1975. 24 pp.

TABLE D-1. CHEMICAL ANALYSES OF AS-RECEIVED SLIMES SOLIDS (30)
(percent)

Chemical analyses	Sample																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	High	Low
Calcium oxide	8.3	12.8	18.5	18.6	18.4	26.9	21.6	16.4	9.1	18.7	18.7	9.6	24.6	11.2	10.1	16.2	26.9	8.3
Phosphorus pentoxide	5.1	8.2	13.7	15.7	16.2	19.7	17.3	11.6	5.9	13.5	11.0	8.3	17.2	8.7	9.7	12.0	19.7	5.1
Equivalent BPL[a]	11.1	17.9	29.9	29.9	35.4	43.0	37.8	25.3	12.9	29.5	24.0	18.1	37.6	19.0	21.2	26.2	43.0	11.1
Calcium oxide / Phorphorus pentoxide	1.63	1.56	1.35	1.36	1.14	1.37	1.25	1.41	1.54	1.39	1.70	1.16	1.43	1.29	1.04	1.35	1.70	1.04
Magnesium oxide	6.7	2.3	4.0	1.5	0.8	2.0	1.4	3.2	3.6	2.7	6.2	1.6	3.0	2.2	1.6	2.9	6.7	0.8
Aluminum oxide	10.3	13.7	12.2	13.5	16.8	10.4	12.9	12.6	12.5	10.7	7.6	12.5	8.2	13.0	12.1	11.9	16.8	7.6
Iron (III) oxide	4.6	4.3	2.5	1.9	1.7	1.6	3.2	2.3	5.5	5.4	2.1	3.3	1.6	8.3	2.8	3.4	8.3	1.6
Silicon dioxide	47.6	46.1	30.4	33.4	28.2	23.1	27.5	33.5	45.8	34.5	34.0	49.1	28.6	39.5	46.6	36.5	49.1	23.1
Sodium monoxide	0.3	0.3	0.2	0.3	0.1	0.2	0.3	0.2	0.3	0.2	0.3	0.3	0.5	0.4	1.2	0.3	1.2	0.1
Potassium monoxide	0.5	1.4	0.6	0.8	0.6	0.6	0.8	0.2	1.3	0.5	0.5	1.5	0.4	1.1	0.8	0.8	1.5	0.2
Fluorine	1.1	1.2	2.3	1.6	1.6	2.2	1.8	1.6	0.7	1.4	1.4	1.0	1.8	1.0	1.2	1.5	2.3	0.7
Carbon	1.1	0.8	1.7	1.0	0.5	1.5	0.5	1.9	1.0	0.6	1.8	0.4	1.0	0.6	0.7	1.0	1.9	0.4
Carbon dioxide	2.2	1.3	5.0	1.5	1.0	3.4	1.3	4.6	2.9	1.2	5.3	0.7	2.2	1.1	1.0	2.3	5.3	0.7
Sulfur	0.22	0.17	0.21	0.31	0.11	0.36	0.12	0.22	0.10	0.14	0.18	0.12	0.31	0.21	0.17	0.20	0.36	0.10

[a] BPL = Bone phosphate of lime (% BPL • 0.4576 = % P_2O_5)

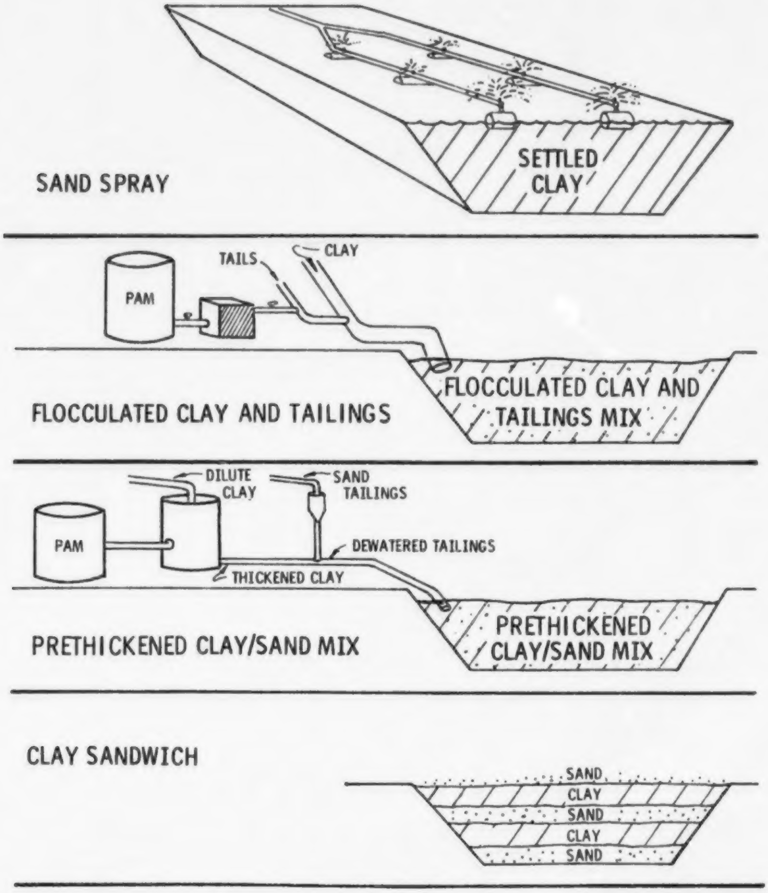
SAND SPRAY
SETTLED CLAY
TAILS
CLAY
PAM
FLOCCULATED CLAY AND TAILINGS
FLOCCULATED CLAY AND TAILINGS MIX
DILUTE CLAY
SAND TAILINGS
PAM
DEWATERED TAILINGS
THICKENED CLAY
PRETHICKENED CLAY/SAND MIX
PRETHICKENED CLAY/SAND MIX
CLAY SANDWICH
SAND
CLAY
SAND
CLAY
SAND

Figure D-1. Current dewatering concepts (13).

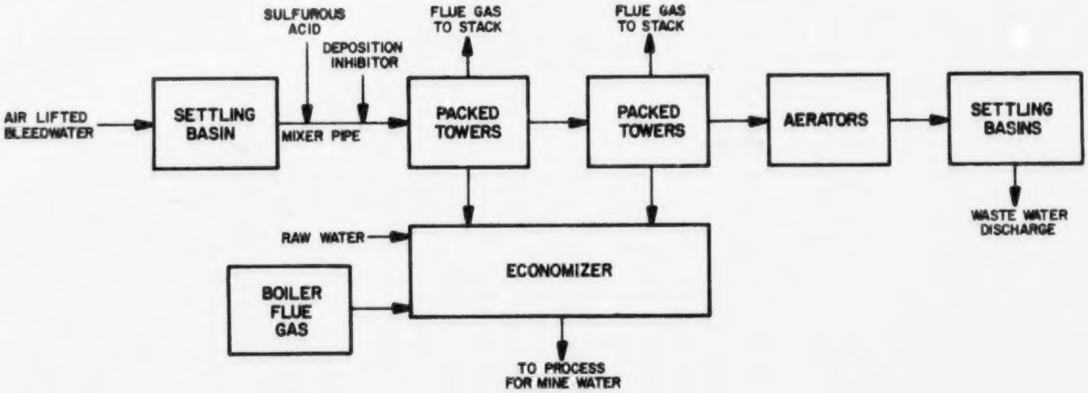
AIR LIFTED BLEEDWATER
SETTLING BASIN
SULFUROUS ACID
DEPOSITION INHIBITOR
MIXER PIPE
FLUE GAS TO STACK
PACKED TOWERS
FLUE GAS TO STACK
PACKED TOWERS
AERATORS
SETTLING BASINS
WASTE WATER DISCHARGE
RAW WATER
ECONOMIZER
BOILER FLUE GAS
TO PROCESS FOR MINE WATER

Figure D-2. Bleedwater treating plant type 1 (3).

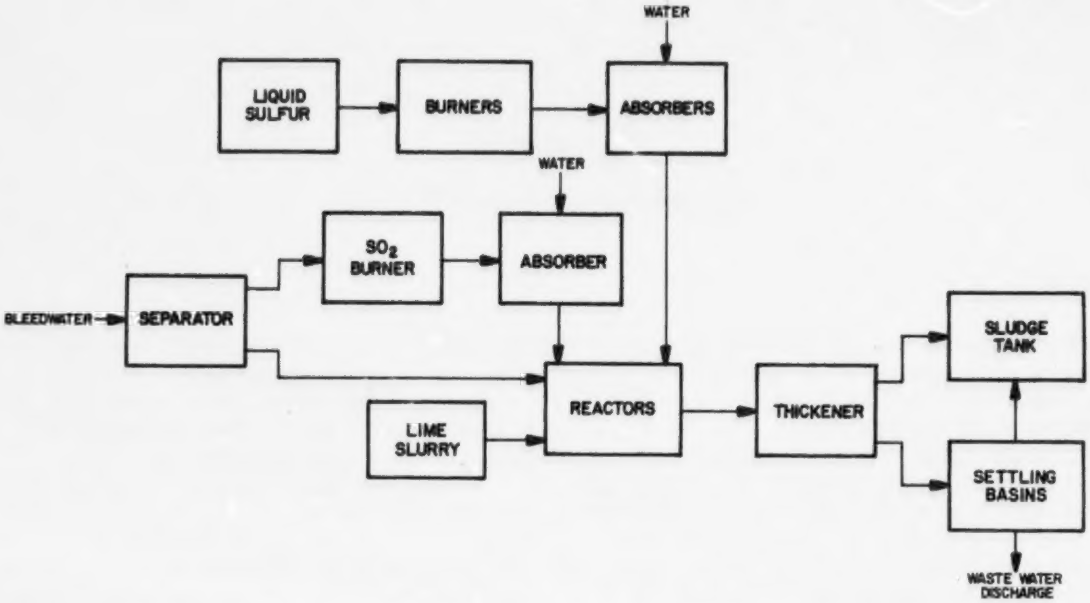
WATER
LIQUID SULFUR
BURNERS
ABSORBERS
WATER
SO2 BURNER
ABSORBER
BLEEDWATER
SEPARATOR
REACTORS
LIME SLURRY
THICKENER
SLUDGE TANK
SETTLING BASINS
WASTE WATER DISCHARGE

Figure D-3. Bleedwater treating plant type 2 (3).

At one offshore salt dome facility, bleedwater is discharged without treatment due to space restrictions. Concentrations of effluents from bleedwater plants are given in Appendix F in Table F-6.

APPENDIX E

HAZARD RATIO CALCULATIONS

AIR

This appendix provides an example of the procedure used to calculate the hazard ratio of maximum time-averaged downwind ground level concentration to an ambient air quality standard and the affected population for respirable particulates. The effect of growth factor and control technology on air emissions is also briefly described. In addition it discusses the hazard ratio of an effluent discharge to water quality criteria.

For ground level sources, the hazard ratio for respirable particulates is given as (31):

$$S_p = \frac{4,020\ Q}{D^{1.814}} \qquad \text{(E-1)}$$

where S_p = hazard ratio for respirable particulates
Q = representative mass emission rate, g/s
D = representative distance from the source, m

For phosphate rock operations, the emission factor for respirable particulates is 37 g/metric ton. The emission rate from a representative plant of 2×10^6 metric tons/yr is the product of the emission factor and the production rate. Assuming that one operating year equals 260 operating days with each day 20 hr long:

$$(385 \text{ metric tons/hr})(37 \text{ g/metric ton}) = 14,230 \text{ g/hr} = 4.0 \text{ g/s}$$

At the representative distance of 400 m, the hazard ratio is calculated from Equation E-1 as 0.30.

The distance at which the hazard ratio equals 0.1 for respirable particulates is computed from Equation E-1, rearranged to:

$$D_{S_p=0.1} = \left(\frac{4,020\ Q}{S_p}\right)^{1/1.814} \qquad \text{(E-2)}$$

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(31) Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio, July 1977. 96 pp.

$$D_{S_p=0.1} = \left[\frac{(4,020)(4.0)}{0.1}\right]^{1/1.814} = 740 \text{ m}$$

The area affected within the boundary of 400 m to 740 m is computed by subtracting the area of a circle with a 400 m diameter from the area of a circle with a 736 m diameter--0.30 km^2. The population affected is the product of the area affected and the population density of 50 persons/km^2 or 15 persons.

The growth factor is the ratio of the calculated 1980 emissions levels to the 1974 levels. Production for 1980 is calculated assuming a 4.7% annual increase (Section 6) from 1974 to 1980. The 1980 production level is thus 54.58 x 10^6 metric tons. The 1980 emissions are calculated by applying the efficiency of the best available control technology to the emission factor for the loading of railroad hopper cars, since this is the major area in the phosphate rock industry where additional control technology is being developed. Assuming that new systems will be able to attain efficiencies of 90% (by weight), the respirable particulates emission factor for railcar loading will be reduced from 161 g/metric ton (Section 6) to 16 g/metric ton.

The new emission factor for total particulates, after applying the best control technology available, is 217 g/metric ton. This represents a 60% reduction from the 362 g/metric ton 1974 level. Multiplying the 1980 production level of 54.58 x 10^6 metric tons by this factor yields emissions of 11,848 metric tons/yr of total particulates in 1980. The ratio of 1980 to 1974 emissions is thus 0.74.

WATER

The concept of a hazard ratio applied to air emissions was considered an excess relative dose or relative environmental burden. The same concept holds true for water discharges (32).

The hazard ratio is defined as:

$$S_W = \frac{V_D C_D}{(V_R + V_D)F} \qquad \text{(E-3)}$$

where S_W = hazard ratio for water effluent

V_D = volumetric flow rate of the discharge

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(32) Eimutis, E. C., T. J. Hoogheem, and T. W. Hughes. Briefing Document: Water Source Severity and Initial Water Prioritization Structures. Draft prepared under EPA Contract 68-02-1874 by Monsanto Research Corporation, Dayton, Ohio, 21 September 1976. 12 pp.

C_D = concentration of the discharge
V_R = volumetric flow rate of the river
F = hazard factor

Table F-4 gives the discharge concentrations at 24 sites (personal communication with John C. Barnett, State of Florida, Department of Environmental Regulation, January 26, 1977). From the table, the following average discharge concentrations were determined for a representative phosphate rock plant: phosphorus as P, 1.08×10^3 mg/m^3; fluoride, 1.72×10^3 mg/m^3; TSS, 11.14×10^3 mg/m^3.

An average discharge flow rate was determined to be 0.147 m^3/s; a case of direct discharge into the Peace River in central Florida was assumed. The average flow rate of the Peace River is 25.8 m^3/s (33). The hazard factors are developed in Reference 34 from EPA water quality criteria or similar data. The hazard factors for phosphorus, fluoride, and TSS are 0.1 g/m^3, 0.19 g/m^3, and 25 g/m^3, respectively (34). Using Equation E-3, the hazard ratios are 0.061 for phosphorus, 0.051 for fluoride, and 0.0025 for TSS.

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(33) Specht, R. C. Phosphate Waste Studies. Bulletin Series No. 32, University of Florida Engineering and Industrial Experiment Station, Gainesville, Florida, February 1950. 26 pp.

(34) Eimutis, E. C., J. L. Delaney, T. J. Hoogheem, S. R. Archer, J. C. Ochsner, W. R. McCurley, T. W. Hughes, and R. P. Quill. Source Assessment: Prioritization of Stationary Water Pollution Sources. EPA-600/2-77-107p, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1977. 132 pp.

APPENDIX F

EFFLUENT CONCENTRATIONS FOR VARIOUS MINERALS AT VARIOUS SITES

TABLE F-1. EFFLUENT CONCENTRATION OF POLLUTANTS FROM BARITE PROCESSING (3)

Effluent source	Site	Effluent flow	Daily average (maximum), g/m^3									
			TDS	TSS	Ammonia	Cadmium	Chromium	Iron, total	Lead, total	Manganese	Nickel, total	Zinc, total
Underground mine	1	760,000[a]	2,950 (6,900)	50 (100)	0.30 (1.0)	0.01 (0.02)	-[b]	0.10 (0.02)	0.01 (0.02)	0.02 (0.10)	0.02 (0.04)	0.01 (0.02)
Dry process		0										
Wet process	1	-[c]	6.0 (8.0)[d]	15 (32)	0.1 (0.5)[e]			0.04 (0.09)	0.03 (0.10)			
Flotation process:												
Tailings pond	1	0 (0.760)[f]	800 (1,271)	3 5	<0.1 (<0.1)	0.004 (0.008)	0.200 (0.400)	0.030 (0.060)	0.020 (0.080)	0.002 (0.008)	0.030 (0.070)	0.005 (0.010)
Clear water pond	1	0 (0.380)[f]	1,000 (1,815)	3 (6)	5 (35)	-[b]	0.100 (0.120)	0.030 (0.070)	0.040 (0.090)	0.004 (0.008)	0.030 (0.070)	0.030 (0.090)

[a] m^3/yr. [b] Not applicable. [c] Not available. [d] pH. [e] Total barium. [f] m^3/min.

TABLE F-2. EFFLUENT CONCENTRATION OF POLLUTANTS FROM FLUORSPAR PROCESSING (3)

Effluent source	Site	Effluent flow, m^3/day	Daily average (maximum), g/m^3											
			pH	Fluoride	Sulfide	TDS	TSS	Cadmium	Copper	Iron, total	Lead, total	Manganese	Nickel, total	Zinc, total
Mine water discharge	1	273												
	2	490												
	3	54												
	4	303												
	5	4,769												
	6	1,892												
Average		1,892	7.5	2.0	0.37	900	35	0.03	0.01	0.27	0.08	0.12	0.20	0.31
Range		54 (4,769)	7.0 (8.0)	1.1 (3.2)	0.37 0.37	353 (2,998)	10 (300)	0.03 0.03	0.01 0.01	0.05 (0.90)	Trace (0.20)	0.10 (0.15)	0.29 0.29	0.02 (1.00)
Heavy media separation	1	-[a]	7.8	3.0			10.0				0.015			0.09
Froth flotation	1	1,212[b]	7.2	5.1			500							
	2	2,608[b]	8.2	9.8			1,800							

[a] Not available. [b] Assumes 80% of process waste as discharge.

TABLE F-3. EFFLUENT CONCENTRATION OF POLLUTANTS FROM LITHIUM MINERALS PROCESSING (3)

Site	Effluent flow, m³/day	Daily average (maximum), g/m³ BOD	TDS	TSS	Phosphorus, as P	Chloride	Sulfate, as S	Aluminum	Iron	Manganese	Silicon	Sodium	Potassium	Fluoride	Lithium	pH
1	830	6	-[a]	-[a]	0.05	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]
2	7,900	1.6	515	14	0.32	28	63	4.2	0.6	1.7	14.6	2929	6.0	2.2	6.3	7.0 (7.5)

[a] Not available.

TABLE F-4. EFFLUENT CONCENTRATION OF POLLUTANTS FROM PHOSPHATE ROCK PROCESSING (3)

Effluent source: Florida operations

Site	Effluent flow, 10^{-3} m³/min Mean	Max	Daily average (maximum), g/m³ Mean pH range	Fluoride	Phosphorus	TSS
1	15,872	56,781	6.2(7.9)	1.67	0.69	7.46
2	9,259	41,640	6.2(8.1)	2.31	0.39	6.01
3	12,893	49,210	6.8(7.9)	1.90	0.78	3.67
4	2,267	13,461	6.3(7.8)	1.66	1.71	5.21
5	12,450	46,791	6.4(8.3)	1.24	2.24	11.20
6	11,606	42,828	6.8(7.9)	1.19	2.54	4.93
7	10,043	35,303	6.0(7.5)	1.97	1.42	9.21
8[b]	12,867	43,381	5.4(7.3)	5.35	5.57	10.83
9[b]	5,841	32,831	6.4(7.7)	7.75	9.83	8.23
10[b]	-[a]	-[a]	6.6(7.2)	5.22	6.76	6.86
11	4,542	-[a]	6.9(7.5)	2.21	1.07	3.14
12	18,927	-[a]	6.7(7.4)	2.14	0.86	2.32
13[b]	16,277	-[a]	6.0(7.4)	2.97	21.73	8.34
14[b]	42,381	752,672	6.5(8.4)	2.26	18.44	26.44
15	7,942	63,216	6.3(9.3)	1.54	1.71	18.28
16[b]	16,190	126,702	4.6(9.3)	1.14	10.08	34.00
17	14,014	89,506	6.0(8.0)	2.42	1.41	7.86
18	25,101	70,216	7.0(8.5)	2.22	1.02	21.65
19	382	2,146	7.1(8.1)	1.65	0.36	19.01
20	1,719	-[a]	7.4		1.94	1.24
21	2,786	-[a]	7.5	1.45	1.07	13.10
22	3,066	-[a]	7.5		0.96	0.18
23	3,115	-[a]	7.5		1.22	0.35
24	3,172	-[a]	7.5	1.30	0.38	16.96

[a] Not available.

[b] This data cannot be considered representative of slime pond/ settling area mine effluent due to mixing with gypsum stack/process water; therefore, it was not included in averaging calculations.

TABLE F-5. EFFLUENT CONCENTRATION OF POLLUTANTS FROM ROCK SALT PROCESSING (3)

Site	Effluent flow, 10^{-3} m^3/min	Daily average (maximum), g/m^3 TDS	Na	Cl	TSS	SO_4	pH
1	2,839	4,660	1,840	2,820	Trace	Trace	[a]
2	105	30,900	7,200	15,700	72	1,400	7.5
3	347	[a]	[a]	18,000	150	370	6.5
4	53	30,200	11,900	18,500	Trace	[a]	[a]
5a	213	53,000 (112,000)	[a]	32,000 (69,000)	470 (4,050)	208	8.5 (9.0)
5b	363	319,000 (323,000)	[a]	182,000 (190,000)	1,870	260	7.6

[a] Not available.

TABLE F-6. EFFLUENT CONCENTRATION OF POLLUTANTS FROM SULFUR PROCESSING (3)

Effluent source: Treated bleedwater effluents

Site	Effluent flow, m^3/day	g/m^3 Alkalinity	Ammonia	BOD	Chloride	COD	Fluoride	Bromide	Hardness	Nitrate	Nitrite
1	4,600	149	0.34	32	14,580	202	1.09	70.5	4,800	<0.2	0.1
2	27,000	145	0.0	3.2	13,725	46	1.22	36.3	4,170	0.01	<0.1
3	19,000	104	<0.2	89.5	5,895	292	0.23	14.2	1,673	<0.2	<0.1
4	38,000	130	0.5	5	25,000	42	0.5	9.0	2,550	0.14	0.007
5	17,000	50	0.4	2.1	15,500	32	0.4	4.5	2,700	0.16	0.003
6	23,000	110	0.4	350	13,732	490	0.5	<0.01	2,500	<0.03	<0.001
7	11,500	76	0.35	6.4	18,250	70	0.2	20	3,075	0.1	<0.003

Site	Effluent flow, m^3/day	Nitrogen-Kjeldahl	Oil and grease	pH	Total phosphorus	Sulfide	Sulfate	TDS	TS	TSS	TVS
1	4,600	0.95	1.2	7.9	0.001	16	684	29,160	30,176	57	46
2	27,000	0.84	0.9	7.6	0.003	0.4	577	26,154	26,387	33	13
3	19,000	5.64	2.4	7.4	0.056	50.9	355	12,882	12,988	95	19
4	38,000	1.3	4.0	7.7	[a]	[b]	1,680	45,625	45,700	30	2,040
5	17,000	0.9	2.0	7.2	[a]	[b]	2,195	28,280	28,300	20	1,015
6	23,000	0.8	11.0	6.1	[a]	[b]	1,700	26,595	26,600	5	1,000
7	11,500	2.0	2.0	8.3	[a]	[b]	1,300	31,610	35,650	40	1,700

Site	Effluent flow, m^3/day	Color point CO units	Specific conductance pmhos	Aluminum	Boron	Cadmium	Chromium	Copper	Iron, total	Magnesium
1	4,600	18	36,774	0.828	4.218	0.037	<0.010	0.018	0.892	897
2	27,000	55	32,365	0.494	3.606	0.012	<0.010	<0.010	0.349	669
3	19,000	83	16,209	0.144	[a]	<0.010	<0.010	0.029	0.083	123
4	38,000	22	61,600	0.500	2.600	<0.080	<0.050	0.040	2.500	33
5	17,000	16	50,000	0.500	0.500	<0.010	0.030	0.020	0.800	26
6	23,000	45	33,000	6.500	1.300	<0.010	<0.020	0.007	5.000	20
7	11,500	15	53,000	1.500	5.000	<0.010	<0.030	0.020	0.700	170

Site	Effluent flow, m^3/day	Manganese	Mercury	Nickel	Lead	Potassium	Sodium	Zinc	Calcium
1	4,600	0.014	0.0005	0.188	<0.100	295	7,933	0.261	304
2	27,000	0.011	0.0003	0.271	<0.100	234	7,917	0.073	290
3	19,000	0.095	0.0004	0.175	<0.100	50	3,708	0.069	403
4	38,000	0.300	<0.001	0.030	<0.050	60	17,200	0.050	970
5	17,000	0.600	<0.001	<0.060	<0.060	21	9,225	0.020	1,025
6	23,000	0.700	<0.001	<0.030	<0.060	20	8,400	0.120	975
7	11,500	0.120	<0.001	<0.050	<0.070	[a]	11,300	0.039	950

[a] Not available. [b] Nil.

TABLE F-7. EFFLUENT CONCENTRATION OF POLLUTANTS FROM TRONA ORE PROCESSING (3)

Effluent source: Process wastewater[a]

Site	Effluent flow, m^3/day	TS	TDS	TSS
			g/m^3	
1	23	9,000	8,300	700

[a] Plans are underway to eliminate this discharge, which is the only one in the industry.

APPENDIX G

SAMPLING AND ANALYTICAL METHODOLOGY

SAMPLING AND ANALYTICAL OBJECTIVES

A phosphate rock processing facility was sampled and analyzed for the following:

- Ground level concentration.
- Meteorological data such as wind speed, direction, and atmospheric stability class.
- Distance from sampler to source.
- Composition of emissions (emphasis on heavy metals).
- Fraction of respirable particulate (less than 7 μm).

Dispersion equations were applied to reduce this data to the following:

- Mass emissions for selected site.
- Respirable emissions (less than 7 μm) for source type.
- Emission factors for U.S. average conditions.
- Composition of emissions.
- Effects of wind speed on emissions.

ATMOSPHERIC DISPERSION MODELING

For the arrangement shown in Figure G-1, let the origin be defined at the source and all remaining points in the usual Cartesian coordinate system. Let Θ be the angle of mean wind speed. Then to find the value of any point y_i perpendicular to the wind direction centerline, the following is computed:

$$m_1 = \tan \Theta \qquad \text{(G-1)}$$

and for point S_i with coordinates x_i, y_i

$$m_1 = \frac{y_i}{x_i} \qquad \text{(G-2)}$$

The angle α is found from

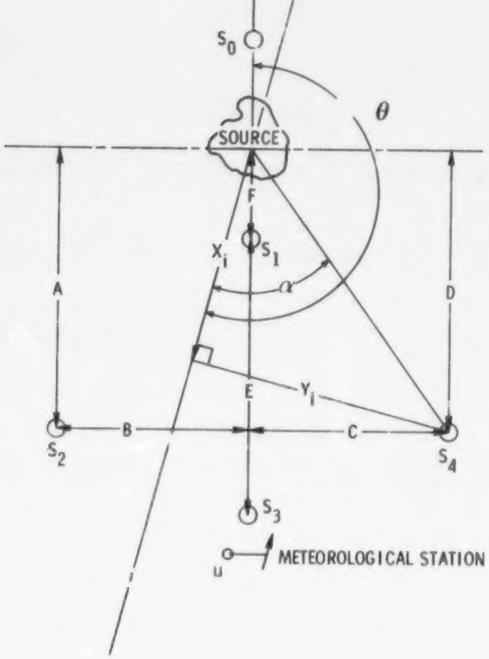
AZIMUTH
S_0
θ
SOURCE
F
X_i
S_1
α
A
D
E
Y_i
B
C
S_2
S_4
S_3
u
METEOROLOGICAL STATION

Figure G-1. Sampling arrangement.

$$\alpha = \arctan \frac{m_2 - m_1}{1 + [(m_1)(m_2)]} \tag{G-3}$$

The lateral distance Y_i is

$$Y_i = (\sin \alpha) \sqrt{x_i^2 + y_i^2} \tag{G-4}$$

and the downward distance X_i is

$$X_i = (\cos \alpha) \sqrt{x_i^2 + y_i^2} \tag{G-5}$$

Estimates of stability class were determined using the procedure described in Figure G-2. The dispersion coefficients σ_y and σ_z can be found in Figures 3-2 and 3-3 of Turner's "Workbook of Atmospheric Dispersion Estimates" (35). The source strength Q will be calculated as an average of the N sampler readings from the following:

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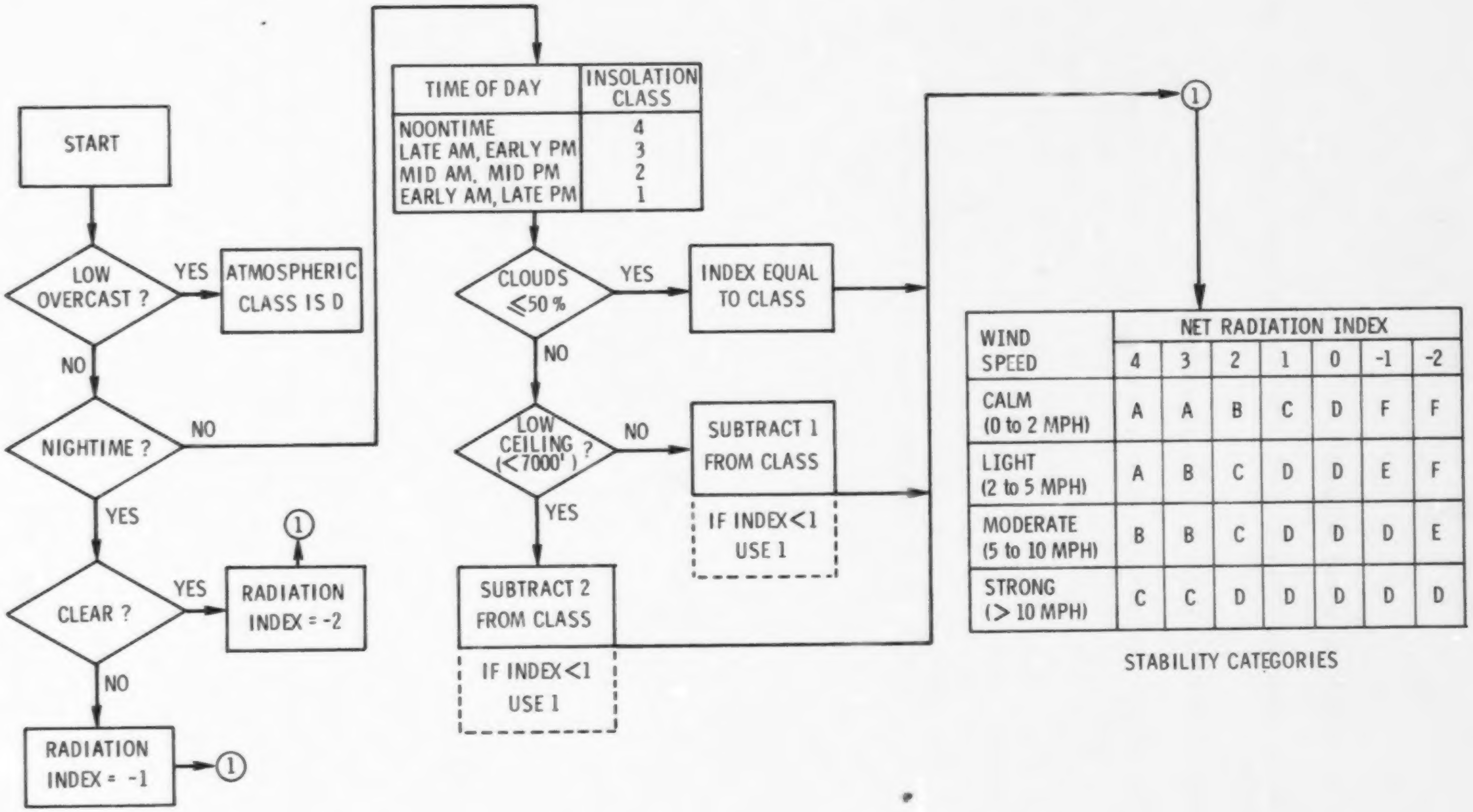
(35) Turner, B. D. Workbook of Atmospheric Dispersion Estimates. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, May 1970. 84 pp.


START
LOW OVERCAST ?
YES
ATMOSPHERIC CLASS IS D
NO
NIGHTIME ?
NO
YES
CLEAR ?
YES
RADIATION INDEX = -2
①
NO
RADIATION INDEX = -1
①
CLOUDS ≤50 %
YES
INDEX EQUAL TO CLASS
NO
LOW CEILING ? (<7000')
NO
SUBTRACT 1 FROM CLASS
IF INDEX<1 USE 1
YES
SUBTRACT 2 FROM CLASS
IF INDEX<1 USE 1
①

TIME OF DAY	INSOLATION CLASS
NOONTIME	4
LATE AM, EARLY PM	3
MID AM, MID PM	2
EARLY AM, LATE PM	1

WIND SPEED	NET RADIATION INDEX						
	4	3	2	1	0	-1	-2
CALM (0 to 2 MPH)	A	A	B	C	D	F	F
LIGHT (2 to 5 MPH)	A	B	C	D	D	E	F
MODERATE (5 to 10 MPH)	B	B	C	D	D	D	E
STRONG (> 10 MPH)	C	C	D	D	D	D	D

STABILITY CATEGORIES

Figure G-2. Flow chart of atmospheric stability class determination.

$$Q = \sum_{i=1}^{n} \frac{\chi_i \pi \sigma_y \sigma_z u}{N \exp\left[-1/2\left(\frac{Y_i}{\sigma_y}\right)\right]^2} \qquad \text{(G-6)}$$

where u = average wind speed

This process was computerized for efficient reduction of experimental data.

FIELD SAMPLING AND ANALYTICAL METHODOLOGY

A Gaussian plume equation was used to estimate the fugitive dust source strength from ground level ambient air samplers. Since the Gaussian plume equation gives a time-averaged description of the concentration field, a number of receptors were used as shown in Figure G-3. The following rationale applies: 1) the position of the sampler determines ambient dust levels and 2) wind direction and velocity were not constant and affect time-averaging results. The positioning of samplers eliminated the need to correct for concentration which varied with time.

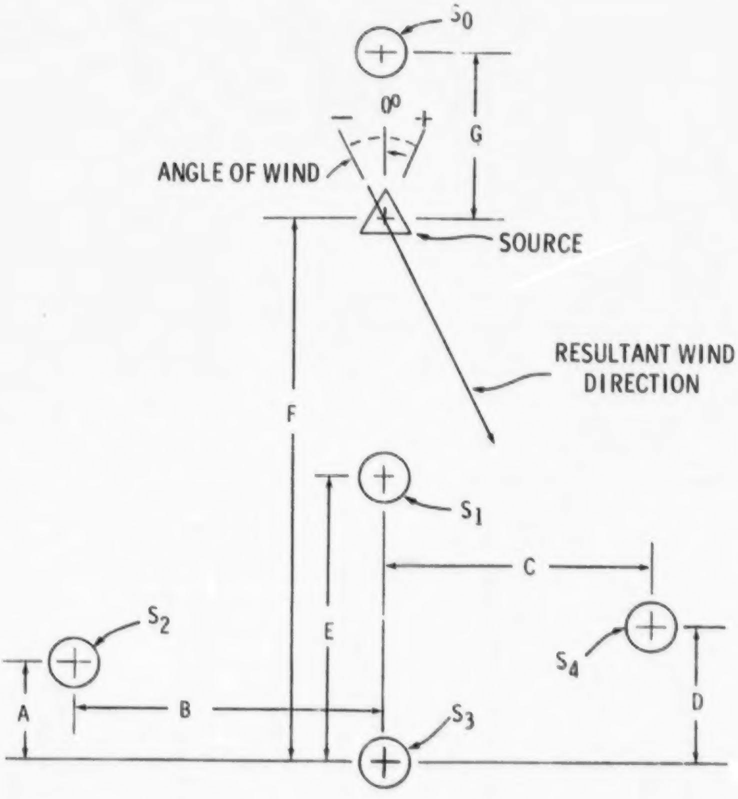


Figure G-3. Sampler positions.

Sampler 1 is the primary source strength estimator and was located as close to the source as possible. This sampler was placed from one to three obstruction heights from the source, depending upon stability class. Sampler 3 is required for correlations with downwind power law decay. Samplers 2 and 4 are required for correlations with lateral dispersion estimates and for estimating proximity to the plume centerline. Sampler 0 was used as a blank to compensate for other dust sources upwind of the site under investigation.

A portable mechanical meteorological station gave the remaining parameter, wind speed. The azimuth was monitored throughout the sampling period. Figure G-4 is a pictoral overview of the integrated sampling and analytical scheme. The filter from Sampler 1 was analyzed by x-ray fluorescence techniques and compared to source materials for composition. A particle count was also made via optical microscopy to check for fibers and to give a different perspective to particle size distribution.

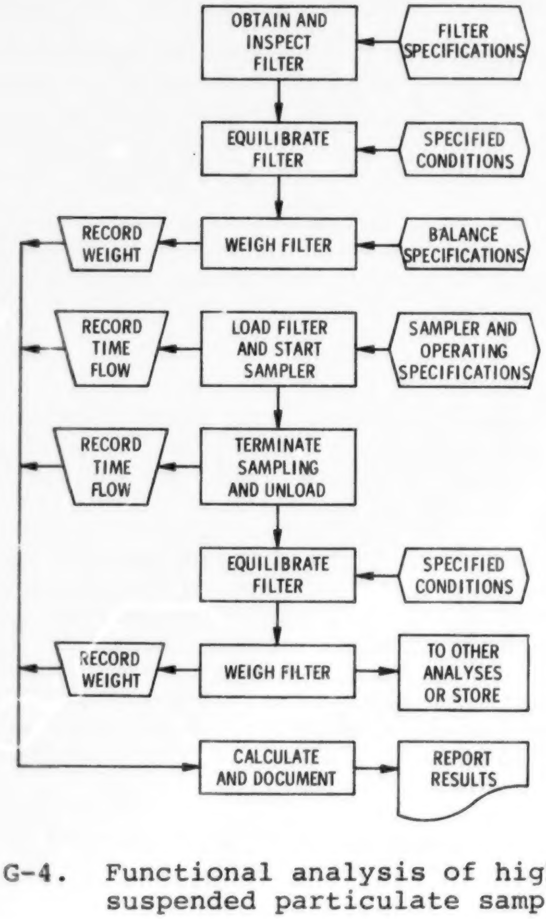

OBTAIN AND INSPECT FILTER
FILTER SPECIFICATIONS
EQUILIBRATE FILTER
SPECIFIED CONDITIONS
RECORD WEIGHT
WEIGH FILTER
BALANCE SPECIFICATIONS
RECORD TIME FLOW
LOAD FILTER AND START SAMPLER
SAMPLER AND OPERATING SPECIFICATIONS
RECORD TIME FLOW
TERMINATE SAMPLING AND UNLOAD
EQUILIBRATE FILTER
SPECIFIED CONDITIONS
RECORD WEIGHT
WEIGH FILTER
TO OTHER ANALYSES OR STORE
CALCULATE AND DOCUMENT
REPORT RESULTS

Figure G-4. Functional analysis of high-volume suspended particulate sampling.

APPENDIX H[a]

SAMPLING MECHANICS AND INDIVIDUAL FIELD TEST DATA

The sampling procedure for fugitive dust may be broken into three segments: 1) sampling preparations, 2) onsite sampling, and 3) data reduction.

SAMPLING PREPARATIONS

These preparations included a check of all equipment used for onsite sampling. The portable electric generators were test run and adjusted to avoid onsite equipment failures. All high-volume air samplers were test run and calibrated, and the weather station was set up and checked for proper operation.

In addition to the equipment check, the filters to be used in the samplers were preweighed (tared) and coded to facilitate data collection. This same weighing and coding was also performed for spare filters which were used to replace others damaged during the trip to and through handling at the site.

Finally, maps and/or aerial photographs were loaned from plant personnel at each sample site. The photographs were used to help plan a sampling strategy, to indicate possible obstructions, and to acquaint the sampling team with the site.

ONSITE PROCEDURE

Sampling was done by a two-man crew with a van containing high-volume samplers and a trailer containing gasoline-engine powered electrical generators, gasoline, weather station, and various lengths of extension cords.

The crew checked with the U.S. Weather Bureau to determine the forecasted cloud cover and the wind direction and velocity. Once onsite, actual wind direction was compared to that forecasted, and then the hi-volume samplers were placed to include the expected wind direction in the sampler matrix. On the first day at a sampling location, the filters were placed in the filter holders while the samplers were still in the van. On subsequent days, the new filters were placed in the samplers immediately after the used ones were removed.

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[a] Nonmetric units are used in this appendix since they correspond to those units utilized during sampling.

With the samplers ready to use, the two-man crew placed the hi-vol sampler with the synchronous motor and flow rate readout in a location on the upwind side of the fugitive emission source to gather the background data needed for the experiment. The background sampler was put into operation as soon as the small electrical generator was started since the concentration of dust on the filter was usually small. A longer run time allowed the filter to collect more dust and made weighing the filter more accurate.

Once the background sampler, S_0, was operating properly, the crew placed the next sampler, S_1, immediately downwind of the source. The distance from the source to the location of S_1 depended on atmospheric stability. Sampler S_3 was placed on a straight line with S_0 and S_1 (along the wind direction). Samplers S_2 and S_4 were were placed to the left and right of S_3, spaced far enough apart to include expected wind fluctuations between S_2 and S_4.

While the last four samplers were being positioned, the weather station was assembled. The 10-ft telescopic pole used to support the instruments needed to record the wind speed and direction was anchored downwind of S_3. The sensors were placed on top of the pole and electrically connected to gauges which give the wind speed in mph, the wind direction in degrees, the ambient temperature, and the barometric pressure. The wind indicator was set with 0° in the direction from which the wind was blowing. Any plus or minus deviation meant that the wind was shifting. Next the large electrical generator was placed downwind from S_3 so that emissions from the generator could not affect the particulate loadings in the hi-vols. The system, S_1, S_2, S_3, S_4 and the weather station, were started, the time was recorded, and the first wind speed and direction were taken. Each sampler was checked for proper operation; the filters were checked to make sure they were completely sealed; and the initial flowrate through the filter was recorded.

Weather data was recorded every 15 min, and high-volume sampler flowrates were recorded every hour. When the gasoline-powered electrical generators needed fuel, the system was turned off and refueling time was indicated on the data sheets.

Once everything was running properly, the crew measured the distances A, B, C, D, E, F, and G (see Figure G-1) and diagrammed the sampling area. Any obvious source of emissions or any obstacle that may have interfered with the testing was noted on the diagram.

After running for at least 4 hr, the equipment was shut down, loaded, and readied for the next set of sampling.

DATA REDUCTION

The fugitive dust-sampling worksheet, Figure H-1, was completed at the beginning of each sample run. It shows the positions of all samplers relative to the source, the atmospheric stability, and which filters were used with which samplers. A fugitive dust sampler and meteorological data log, Figure H-2, was completed during the sample runs at 15-min intervals. It shows the conditions under which sampling was conducted.

Figure H-3 is the worksheet used at the laboratory to determine the ambient concentration of dust at each of the sampler positions during the sample run. The input data for these calculations were taken from Figure H-1, Figure H-2, and the filter weights determined prior to sampling. The concentrations from the worksheet, the meteorological data, and the sampler positioning measurements were entered on a third table, Figure H-4. Figure H-4 shows the collected data in a simplified form, including the results of the particle size analysis (see Table H-1) performed at the laboratory. The data from Figure H-4 was then input to the dispersion equation to calculate source strengths and emission rates for each sample run.

Finally, the particles collected during each sample run were analyzed. The chemical compositions were used to determine the toxicity of the emissions and were compared with samples of process materials. These analyses and comparisons are presented in Table H-3.

The concentration of fluoride compounds in the particulates, reported as fluorine, averages about 5%. The composition of a sample of the rock being mined is not significantly different.

INDIVIDUAL FIELD TEST DATA

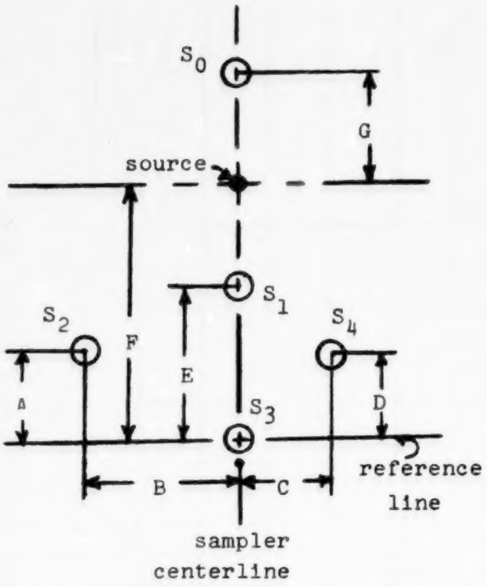
This section shows the field data and analytical results for the plant sampled. Table H-2 shows the meteorological conditions, fugitive dust concentrations, and sampler positions (as related to Figure H-1) for each test run. Table H-3 gives the analytical results for each sample run.

Six sample runs were made at one site from April 8 through 15, 1974. The data collected during one of the tests was discarded because of excessive change in the wind direction (66°). The reference point for the sampler setups was the storage and loading area; however, because the sampler positions changed considerably from one sample run to the next, emissions from different parts of the process would dominate the results of different sample runs. This is shown in the wide range of calculated emission rates (56 lb/hr to 250 lb/hr).

Run No.__________
DATE__________

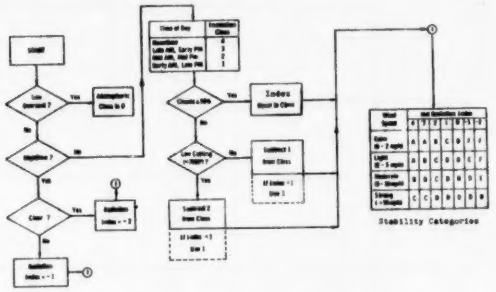
actual barometric pressure __________"Hg

dry bulb ______ °F ______ °F
wet bulb ______ °F ______ °F



S_0
G
source
F
S_1
E
S_2
A
S_3
S_4
D
B
C
reference line
sampler centerline

ATMOSPHERIC STABILITY DETERMINATION



Yes
No
Clear ?
Index
Stability Categories

A __________ ft. (measured)
B __________ ft. "
C __________ ft. "
D __________ ft. "
E __________ ft. "
F __________ ft. (estimated)
G __________ ft. "

TIME ______ STABILITY ______
" ______ " ______
" ______ " ______
" ______ " ______

COMMENTS:

Sampler	Filter No.	Sampler No.
S_0		
S_1		
S_2		
S_3		
S_4		

obtain sample of source before signing sheet

Sampling crew __________
____
____

Figure H-1. Fugitive dust sampling worksheet.

Date____ Run_____ Page_____

Time (24 hr. clock)	Wind				S_1		S_2		S_3		S_4		Other comments
	Speed		Direction										
	mph		Compass degrees										
	avg.	range	avg.	range	Roto cfm	Act cfm	Roto cfm	Act cfm	Roto cfm	Act cfm	Roto cfm	Act cfm	
Totals													
Average													
Total elapsed time													Sampling crew

Sampling crew
______
______
______

Figure H-2. Fugitive dust sampler and meteorological data log.

DATE ________ SOURCE ________ RUN NO. ________

Calculate			S_0	S_1	S_2	S_3	S_4
		Filter No.					
	a	Final Wt. (mg)					
	b	Tare (mg)					
a − b =	c	Net Wt. (mg)					
	d	Flow Rate (avg CFM)					
	e	Sample Time (Minutes)					
d × e =	f	Total Volume (Cubic Feet)					
$\frac{35310 \times c}{f}$ =	g	Concentration ($\mu g/m^3$)					

PARTICLE SIZE ANALYSIS

Calculations By ________

Figure H-3. Fugitive dust calculation worksheet.

Run No. ____________

Wind Speed						
Wind Direction						
Wind Direction range						
Atm. Stability						
Distance	A					
"	B					
"	C					
"	D					
"	E					
"	F					
"	G					
Wet Bulb						
Dry Bulb						
Barometric Pressure						
Concentration at	S_o					
"	S_1					
"	S_2					
"	S_3					
"	S_4					
% Dust > 7u						

Figure H-4. Summary of meteorological data, sampler positions, and ambient concentrations.

TABLE H-1. PHOSPHATE ROCK

Loose particles: Size range, μ	Loose particles: Number of particles	Loose particles: Weight, %	Filter particles: Size range, μ	Filter particles: Number of particles	Filter particles: Weight, %
Sample 5					
0 to 2.3	63	0.02	0 to 1.2	84	1.41
2.3 to 4.6	89	0.21	1.2 to 2.4	103	10.08
4.6 to 9.2	54	1.08	2.4 to 4.8	49	38.38
9.2 to 18.4	36	5.73	4.8 to 9.6	8	50.13
18.4 to 36.8	17	21.65	9.6 to 19.2	0	0
36.8 to 73.6	7	71.31			
73.6 to 147	0	0			
			Fibers: 0		
Sample 6					
0 to 2.3	51	0	0 to 1.2	104	0.97
2.3 to 4.6	77	0.04	1.2 to 2.4	81	4.41
4.6 to 9.2	54	0.25	2.4 to 4.8	33	14.39
9.2 to 18.4	43	1.60	4.8 to 9.6	7	24.42
18.4 to 36.8	10	2.98	9.6 to 19.2	2	55.81
36.8 to 73.6	8	19.07	19.2 to 38.4	0	0
73.6 to 147	4	76.06			
147 to 294	0	0			
			Fibers: 1		

TABLE H-2. FIELD SAMPLING DATA FROM PHOSPHORUS ROCK PROCESSING

	Run No. 1	Run No. 2	Run No. 3	Run No. 4	Run No. 5	Run No. 6
Wind speed, mph	6.6	6.4	7.7	14.0	8.9	6.25
Wind direction, °	21.3	-57.7	-3.0	-11.3	-7.9	15.1
Wind direction, range, °	51.6	65.7	35.8	30.7	42.0	42.5
Atmospheric stability	A	A	B	C	C	A
Distance, ft:						
A	42	0	-210	48	108	72
B	198	159	150	225	90	223
C	126	144	237	213	129	135
D	54	-14	-210	72	129	90
E	135	147	228	294	267	144
F[a]	800	600	579	2,300	500	350
G[a]	2,200	2,500	4,500	3,500	2,000	2,500
Wet bulb, °F	65	63	62	66	73	75
Dry bulb, °F	79	74	80	84	88	88
Barometric pressure[b]	30.35	30.22	30.42	30.46	30.35	30.29
Concentration, μg/m^3:						
S_0	35.7	37	85	105	63	70
S_1	221	357	1,407	223	1,276	1,623
S_2	393	146	668	107	1,052	1,834
S_3	290	257	1.028	241	1,009	1,433
S_4	238	347	690	320	870	829
Source strength, Q[c]	169.3 ± 67.6	–[d]	82.16 ± 40.82	250.2 ± 166.6	55.63 ± 5.35	126.6 ± 86.1
Elevation	30	30	30	30	30	30

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[a] Estimated within 10% from transit. [b] Barometer pressure is for use in comparing different runs.

[c] Q is from computer. [d] No good.

TABLE H-3. PHOSPHATE ROCK PROCESSING

Material	Sample sample, %	Run 3, %	Run 5, %	Run 6, %
Aluminum	2.11	2.5	2.93	3.19
Calcium	41.4	60.0	49.8	59.5
Chlorine	—[a]	—[a]	—[a]	—[a]
Chromium	—[a]	—[a]	—[a]	—[a]
Fluorine	3.82	5.8	5.1	6.4
Iron	2.47	1.6	1.46	2.13
Magnesium	0.09	0.2	0.73	0.75
Manganese	0.11	—[a]	—[a]	—[a]
Phosphorus	32.6	25.5	25.6	22.4
Potassium	0.14	0.08	0.07	0.11
Silicon	5.45	4.1	13.9	5.3
Sodium	0.40	—[a]	—[a]	—[a]
Sulfur	—[a]	—[a]	—[a]	—[a]
Titanium	1.10	0.16	0.15	0.21

Run number	Minutes run	Total particulate emission rate, lb/hr	Standard deviation, lb/hr	Confidence limits
1	232	169.3	±67.6	±124.4
2	265	[b]	[b]	[b]
3	350	82.16	±40.82	±75.0
4	320	250.2	±166.6	±306.1
5	245	55.6	±5.35	±9.83
6	239	126.6	±86.1	±158.2

Run number	Particle size distribution	Emission factor, lb/ton	Comments on run
1	10.11% <7 μ	0.434	—[c]
2		—[b]	Excessive wind change.
3		0.210	Storage.
4		0.639	Total.
5		0.142	Drying.
6		0.322	—[c]

[a] None detected. [b] No good. [c] Not applicable.

NOTE.—Compositions were calculated after drying.

GLOSSARY

alluival: Clay, silt, gravel, sand, or similar material deposited by running water.

apatite: Any of a group of calcium phosphate minerals of the approximate general formula $Ca_5(F, Cl, OH, \frac{1}{2}CO_3)(PO_4)_3$.

azimuth: Horizontal direction expressed as the angular distance between the direction of a fixed point (as the observer's heading) and the direction of the object.

bleedwater brine: Water from bleedwater wells which are drilled by the sulfur industry to control dome pressure and allow for continuous introduction of hot water to the sulfur formation.

confidence level: Range over which the true mean of a population is expected to lie at a specific level of confidence.

criteria pollutant: Pollutant for which ambient air quality standards have been established.

dragline: Type of excavating equipment which casts a rope-hung bucket a considerable distance, collects the dug material by pulling the bucket toward itself on the ground with a second rope, elevates the bucket, and dumps the material on a spoil bank, in a hopper, or on a pile.

dolomite: Mineral consisting of a calcium magnesium carbonate ($CaMg[CO_3]_2$) found in crystals and in extensive beds as a compact limestone.

emission burden: Ratio of the total annual emissions of a pollutant from a specific source to the total annual state or national emissions of that pollutant.

fibrosis: Abnormal increase in the amount of fibrous connective tissue in an organ or tissue.

free silica: Crystalline silica defined as silicon dioxide (SiO_2) arranged in a fixed pattern (as opposed to an amorphous arrangement).

froth flotation: Process used to treat ore which produces one or more concentrates of valuable minerals and a tailings composed of waste or less valuable minerals.

fugitive emission: Either gaseous or particulate emissions from industry-related operations that escape to the atmosphere without passing through a primary exhaust system.

gangue: Waste material.

hazard factor: Measure of the toxicity of prolonged exposure to a pollutant.

hazard ratio: Hazard potential of a representative source defined as the ratio of a concentration to the hazard factor.

jig: Mechanical device used for separating materials of different specific gravities by the pulsation of a stream of liquid flowing through a bed of materials.

noncriteria pollutant: Pollutant for which ambient air quality standards have not been established.

quarrying: Activity in an open or surface mine.

representative source: Source that has the average emission parameters.

respirable particulates: Those particles with a geometric mean diameter less than or equal to 7 µm.

screen: Mesh used to separate stone into various sizes.

silicosis: Chronic disease of the lungs caused by the continued inhalation of silica dust.

slimes: Fine clay slurry of about 3% to 5% solids content.

sluice pit: Trough into which the phosphate matrix is slurried.

submerged-combustion evaporator: Evaporation unit which consists of a tank to hold the liquid, a burner and gas distributor that can be lowered into the liquid, and a combustion-control system.

sump: Lowest part of a mine shaft into which water drains.

threshold limit value: Concentration of an airborne contaminant to which workers may be exposed repeatedly, day after day, without adverse affect.

Trommel circuit: Circuit of cylindrical or conical revolving screens used for sizing of rock.